HUMAN PHYSIOLOGY,

STATICAL AND DYNAMICAL;

OR,

THE CONDITIONS AND COURSE

OF THE

LIFE OF MAN.

BY

JOHN WILLIAM DRAPER, M.D., LL.D.,

PROFESSOR OF CHEMISTRY AND PHYSIOLOGY IN THE UNIVERSITY OF NEW YORK;
AUTHOR OF A "HISTORY OF THE INTELLECTUAL DEVELOPMENT OF EUROPE,"
"THOUGHTS ON THE FUTURE CIVIL POLICY OF AMERICA," ETC., ETC.

WITH NEARLY 300 WOOD ENGRAVINGS.

SEVENTH EDITION.

NEW YORK:
HARPER & BROTHERS, PUBLISHERS,
FRANKLIN SQUARE.
1878.

PREFACE TO THE SEVENTH EDITION.

ANOTHER edition of this work being required, I take the opportunity of returning my thanks to the medical profession and the public for their continued favor.

A recent and thorough examination of it enables me to say that I believe it will be found to present the Science of Physiology in its most modern form.

It is intended to give an exposition of the Physiology of Man, considered as an individual, and may be looked upon in that respect as a work complete in itself.

But man is also a member of society, and, as has been remarked in previous editions, History is in truth only a branch of Physiology. This is the point of view from which I have regarded the subject in my "History of the Intellectual Development of Europe," a work which, taken together with this, is intended as a treatise on the entire range of human relations, individual and social.

The remarkable favor with which that portion of the work has also been received, both in America and Europe, several editions, translations, and reprints having been called for in the course of a few months, satisfies me that the views here indicated meet with approval.

For the encouragement so shown to these works I again return my sincere thanks.

New York, 1865.

PREFACE TO THE SECOND EDITION.

Two years ago the first edition of this work was published. Since that time several thousand copies have been disposed of; it has been introduced as a text-book in many of our medical schools, and has been very favorably received by the profession and the public.

I have therefore felt it necessary to submit it to a careful examination, for the purpose of removing any errors it may contain, and improving it as far as its present form admits. The revision it has undergone will, I hope, make it worthy of the continued patronage of those who have hitherto shown it so much encouragement.

In these corrections I have availed myself of many of the suggestions made in various reviews of the original work, and take this occasion to express my thanks for the consideration shown toward it both in America and Europe. No one knew better than myself how numerous were its imperfections. The manner in which they have been overlooked has served to convince me that those who were judges of the science, and could deal authoritatively with it, were disposed to encourage any attempt at its improvement, even though that attempt was marked by many conspicuous shortcomings.

For doubtless they saw that this book aimed at much more than was directly expressed upon its pages. To treat Physiology as a branch of Physical Science; to exclude from it all purely speculative doctrines and ideas, the relics of a philosophy (if such it can be called) which flourished in the Middle Ages, though now fast dying out, and from which the more advanced subjects of human knowledge, such as Astronomy and Chemistry, have long ago made themselves free—to do this, amounts, in reality, to a reorganization and reconstruction: a task of extreme difficulty, and for complete success demanding the conjoint labors of many philosophers and many physicians.

At the best, therefore, such an attempt, embracing the whole science, made by a single individual, must needs be unsatisfactory, if any thing like a rigorous criticism be applied. And yet it may be truly said that the interest of the medical profession at the present time requires that such encouragement as this work has received should be extended to every undertaking of the kind. I hope that the success which has in

this manner attended my labors may prove an encouragement to others to devote themselves with better results to a similar task.

To physicians I would earnestly address myself, in the hope of obtaining their continued aid and hearty patronage for every such attempt. I would ask them why it is that we never hear of empiricism in Natural Philosophy, Engineering, Astronomy? Is it not because the principles upon which those subjects rest have ceased to be speculative, and are restricted to the demonstrative, the experimental, the practical? In Philosophy, sects only arise while principles are uncertain; in Medicine, the quack only exists because there is a doubt. And considering the condition to which the medical profession in our times has come, considering its decline in social estimation, and its shortcomings even in its own judgment—is it not the duty of every physician to inquire into the causes of such a state?

If a watch is to be mended, or a steam-engine repaired, do we not apply the principles of common sense to the case? Who ever heard of sects among watchmakers, or quacks among engineers? If we will only apply ourselves in a right spirit to its study, there is nothing more mysterious or incomprehensible in a living organism than there is in such mechanical contrivances. There is nothing in the structure of man which the intellect of man can not understand. It is this, indeed, which constitutes his chief glory, and makes him a worthy representative of the wisdom and power of his Creator.

As in any mechanical contrivance, so in ourselves, imperfections and disarrangements can only be repaired by a knowledge of the construction of the parts, and their manner of working. The practice of Medicine must rest on an exact Anatomy and a sound Physiology. As soon as it is brought to this, empiricism will disappear of itself; it will need no legal enactments, no ethical codes for its destruction. And for this reason, if there were no others, it is the bounden duty of every physician to encourage to the utmost within his own sphere of influence every attempt to realize such a state of things. The encouragement which has been given to this book I regard as a token that these principles are profoundly recognized by the medical profession of our country.

To students of Medicine I may be permitted, on this occasion, to say a few words. It was chiefly with the hope of influencing them, and guiding them into the paths of scientific Physiology, that I was first induced to write this book. I would impress on them the importance of cultivating habits of thought arising from the exact and practical sciences. A great revolution is impending over the profession to which they have devoted themselves. If they design to take a leading position, not merely following it as an industrial pursuit, but regarding it as one of the most dignified and noble of human occupations, they must

prepare themselves in a manner consistent with the modes of thought that must prevail in the times now quickly approaching. It may be too much for us to expect that our contemporaries, who have been educated in the ideas of the past, should unlearn so much of what they have learned, should in so many things begin their studies again; but we may demand a right preparation from those who are only now commencing. In offering to them this book, I do not present an untried work. It is the result of an experience in teaching for many years, an attempt to set forth in plain language the great features of the science, and to give in sufficient detail a representation of the present state of Physiology. For the purpose of facilitating its study, I have divided the whole subject into two branches, Statical and Dynamical. The expediency of this has been impressed upon my attention by the necessity of conforming the course of lectures of which these pages are an abstract, to the wants of a medical class. The physician is chiefly concerned with the conditions of life—the organic functions, as digestion, respiration, secretion, etc. The doctrines of development and the career of an organic form are of less pressing interest; but it was very soon found that other advantages were derived from this subdivision, as might have been expected from its conformity to the usages of writers on other branches of Physical Science.

To the general reader I may remark that I have endeavored to carry out in the following pages the spirit of what is contained in the preceding paragraphs. I have devoted more than twenty years not merely to the study, but also to the experimental determination of physiological questions, of which only a summary could here be offered. It was not possible to give my own results more in detail in a formal text-book on the entire science, but it may not perhaps be improper here to say that opinions sometimes delivered in a few lines have cost me many days, or even weeks, of expensive and laborious experiment.

Among the contemporary works I have used as authorities are Dr. Carpenter's different treatises, Todd and Bowman's Physiological Anatomy, and Kirke's and Paget's Hand-book. As respects monographs, the language of the authors themselves has been employed wherever it was possible. A list of wood-cuts is annexed, in which reference is given to the sources from which those not original have been derived. In the explanation of these engravings the description used is that of the authors themselves in most cases, and it is incorporated in the text, as, for instance, in Book I., Chapter XVII., in which, the engravings being derived from the Neurology of Leveillé and Hirschfield, the accompanying descriptions are merely translations from the French; or, again, in Book II., Chapter VII., in Dr. Prichard's statements of the methods of examining the skull. With respect to the original engravings, it will be seen that many have been obtained by the aid of microscopic photog-

raphy, the process having been so far improved by me as to be made very available for these uses. For several of the specimens from which photographs have been taken I am indebted to Mr. Abbott.

In this work I have therefore endeavored to treat of man according to the methods accepted in Physical Science, but still of man as an individual only. Physiology, however, in its most general acceptation, has another department connected with problems of the highest interest. Man must be studied not merely in the individual, but also in the race. There is an analogy between his advance from infancy through childhood, youth, manhood, to old age, and his progress through the stages of civilization. In the whole range of human study there are no topics of greater importance, or more profound, than those dealt with in this second department or division. It is also capable of being treated in the same spirit and upon the same principles as the first. I have nearly completed a volume, which will serve as a companion to this, in which in that manner the subject is discussed, and the laws which preside over the career of nations established, and would bespeak for it the consideration of the reader.

JOHN W. DRAPER.

University, New York, July 1st, 1858.

CONTENTS.

BOOK I.

STATICAL PHYSIOLOGY.

CONDITIONS OF LIFE.

CHAPTER I.

Conditions of Life.—Nature and Sources of Substances supplied to the Body.—Annual Quantities required.—Table of Physiological Standards.—Animals do not create, but transform Substances.—Properties and Quantities of Matters received by the System.—Properties and Quantities of those it restores.—Heat of the Body arises from Combustion.—Cooling Agencies in an Animal.—Necessity of Repairs in the System.—Physical Aspect of Man.—The Soul.—The Vital Principle.—Importance of Physical Science to Physiology.................................... Page 9

CHAPTER II.

OF FOOD.

The natural Subdivisions of Physiology.—Of Food: its Sources and Classification—its Value not altogether dependent on its Composition.—Of Milk: its Composition, and Use of its Water, Casein, Sugar, Butter, and Salts.—Variations in the Composition of Milk.—Of Bread.—Of mixed Diets.—Of the embryonic Food of Birds.—Nutrition of carnivorous and herbivorous Animals.—Food formed by Plants and destroyed by Animals.—Uses of mixed Food and Cooking.—Absolute Amount of Food.. 26

CHAPTER III.

OF DIGESTION.

TISSUE-MAKING OR HISTOGENETIC DIGESTION.

Nature of Digestion.—The Mouth, Teeth, Stomach.—The Salivary Glands.—Different Kinds of Saliva.—Properties of mixed Saliva: its Quantity, Composition, and Functions.—Relation of the Salivary Glands and Kidneys.—The digestive Tract.—The Stomach.—Gastric Juice.—Organs for its Preparation.—Manner of producing Chyme.—Influence of the Nerves.—Artificial Digestion.—Preparation and Properties of Pepsin.—Regional and functional Divisions of the Stomach in Animals and in Man.—Object of Stomach Digestion.—Peptones.—Use of Salt.—Digestibility of various Articles of Food... 40

CHAPTER IV.

OF CALORIFACIENT OR INTESTINAL DIGESTION.

Nature of Intestinal Digestion.—Structure of the Intestine.—Digestive Fluids of the Intestine.—The Pancreatic Juice.—The Enteric Juice.—Juice of Lieberkuhn.—Secretion of Peyer's Glands.—Bile.—Digestion of the Carbohydrates and Hydrocarbons.—Properties and Varieties of Lactic Acid.—Doctrine of the Effects of Acidity and Alkalinity of the Digestive Juices.—Illustration of Intestinal Digestion from the making of Wine.—Making of Bread.—Influence of Heat over Ferments.—Comparison of Gastric and Intestinal Digestion.—Changes of the Intestinal Contents.—The Fœcal Residues.. 67

CHAPTER V.

OF ABSORPTION.

Double Mechanism for Absorption.—The Lacteals and Veins.—Lacteal Absorption.—Description of a Villus.—Analogies in Plants.—Introduction of Fat by the Villi.—The Chyle.—Causes of the Flow of Chyle.—Intermediate Changes on its Passage to the Blood.—Action of Peyer's Bodies.—Lymphatic Absorption.—Nature of Lymph.—Structure of the Lymphatic System.—Comparison of Chyle, Lymph, and Serum.—Function of the Lymphatic System.—Production of Fibrin.—Cutaneous Absorption.—Causes of the Flow of Lymph.—Apparent selecting power of the Absorbents.—Connection of the Lacteals and Lymphatics with the Locomotive and Respiratory Mechanism.............Page 84

CHAPTER VI.

ABSORPTION BY THE BLOOD-VESSELS.

Proof of Absorption by the Blood Capillaries.—Occurs as a physical Necessity.—Nature of Capillary Attraction.—Its Phenomena in the Rise and Depression of Liquids.—Conditions for producing a Flow in a Capillary Tube.—Passage of Liquids through minute Pores.—General Propositions respecting Capillary Attraction.—Endosmosis and Exosmosis.—They depend on Capillary Attraction.—Force against which these Movements may take place.—Illustrations of selecting Power.—General View of the entire Function of Absorption, lacteal and venous.... 102

CHAPTER VII.

OF THE BLOOD.

The Offices and Relation of Blood in the System.—The Plasma and Cells.—General Properties and Composition of the Blood.—Quantity in the Body.—Coagulation.—Blood-cells.—Their successive Forms.—The perfect Cell.—Hæmatin: its Properties.—Number of Blood-cells.—Plasma: its Composition, and Variations of its Ingredients.—Albumen, Fibrin, Fat, Sugar.—Mineral Ingredients of the Cells and Plasma compared.—Gases of the Blood.—Changes occurring during the Circulation.—General Functions of the different Ingredients of the Blood.—Introduction of Oxygen by the Cells.—Their transient Duration.............. 111

CHAPTER VIII.

OF THE CIRCULATION OF THE BLOOD.

The Heart as a Machine.—Inadequacy of Harvey's doctrine of the Circulation.—Physical Principle of the Circulation; applied in the case of a Nucleated Cell, Pervious Tissue, Motion of Sap and of Blood.—Dependence of the Circulation on Respiration.—Forms of Circulation: Systemic, Pulmonary, Portal.—Description of the Heart; its Movements.—Their Force, Number, and Value.—Sounds of the Heart.—Cause of its Contractions.—Description of the Arteries, Capillaries, Veins.—Explanation of the Circulation of the Blood.—Facts supporting it.—The First Breath.............. 129

CHAPTER IX.

OF RESPIRATION.

Respiration introduces and removes aerial Substances.—Coalescence of Respiratory and Urinary Organs in Fishes.—Physical and chemical Conditions of Respiration.—Interstitial Movements of Solids, Liquids, and Gases.—Condition of Equilibrium in the Diffusion of Gases.—Condensing Action of Membranes.—Forms of Respiratory Mechanism.—The Lungs of Man.—Three Stages in the Introduction of Air: Atmospheric Pressure, Diffusion of Gases, and Condensation by Membranes.—Exchange of Carbonic Acid for Oxygen.—Divisions of the Contents of the Lungs.—Variations in the expired Air.—Removal of Water.—Effect of irrespirable Gases.—Experiments of Regnault and Reiset.—Nervous Influence concerned in Respiration.—Results of Respiration.............. 149

CHAPTER X.

OF ANIMAL HEAT.

Participation of Organic Forms in external Variations of Temperature.—Mechanism for counterbalancing these Variations.—Development of Heat in Plants at Germination and Inflorescence.—Its Cause is Oxidation.—Connection of Respiration and Heat.—Temperature of Man.—His Power of Resistance.—The diurnal Variations of Heat.—Connection of these Variations with organic Periodicities.—Annual Variations of Heat.—Control over them by Food, Clothing, and Shelter.—Source of Animal Heat.—Effect of Variations in the Food and in the respired Medium, both as respects its Nature and Rarefaction.—Hybernation.—Starvation.—Artificial Reduction of Temperature by Blood-letting.—Principles of Reduction of Temperature.—Radiation.—Contact.—Evaporation.—Their Balance with the Heating Processes.—Local Variations eliminated by the Circulation.—Control by the Nervous System.—Its physical Nature.—Allotropism of Organic Bodies .... Page 175

CHAPTER XI.

OF SECRETION.

SEROUS, MUCOUS, AND HEPATIC SECRETIONS.

Object of Secretion.—Type of secreting Mechanism.—Filtration and Cell Action.—Of Serous Membranes and their Secretions.—Of Mucous Membranes and their Secretions.—Of Hepatic Secretions.—The Liver: its Development and Structure.—Source, Quantity, Composition, Uses, and Flow of the Bile.—Existence of biliary Ingredients in the Blood.—Production of Sugar and Fat in the Liver.—Changes of the Blood-cells in it.—General Summary of the four-fold Action of the Liver: it produces Sugar and Fat, eliminates Bile, is the Seat of the final Destruction of old Blood-cells, and of the Completion of new Ones.—Of the ductless Glands.—The Spleen: its Functions 189

CHAPTER XII.

OF EXCRETION.

THE URINE, MILK, AND CUTANEOUS EXCRETIONS.

Secretion and Excretion.

Of the Kidney: its Structure and Functions.—The Malpighian Circulation.—The Urine: its Ingredients, their Variations and Sources.—Abnormal Substances in it.—The Water and Salts exude by Filtration.—The Cells remove unoxidized Bodies.—Manner of Removal of the Liquid from the Malpighian Sac.

Of the Mammary Gland: its Structure.—Colostrum and Milk.—Ingredients of Milk and their Variations.—Influence of Diet.—Inquiry into the Origin of the Ingredients of the Milk, its Fat, Casein, Salts, Sugar.—Manner of Action of the Gland by Strainage.

Of the Skin.—Structure of its Epiderma and Derma.—Sudoriparous and Sebaceous Glands.—Nails.—Hair.—Ingredients of Perspiration.—Exhalation: its Amount.—Causes of the Variable Action of the Skin.—Its Double Action.—Absorption by the Skin.—General Summary of the Cutaneous Functions 213

CHAPTER XIII.

OF DECAY AND NUTRITION.

Of Decay: Loss of Weight in Starvation.—Interstitial Death.—Effect of Allotropism.

Of Nutrition: Nutrition for Repair and Nutrition for Remodeling, illustrated in the cases of Fat and Bone respectively.

Of Fat: Its Peculiarities, modes of Occurrence, and Origin.—Inquiry whether Animals ever form Fat.—Artificial Production of it.—Animals both collect it and make it.—Accumulation of it expends Nitrogenized Tissue.—Conditions of the Fattening of Animals.—Summary of the Sources, Deposit, and manner of Removal of Fat.—Its partial Oxidations.—Summary of its Uses.—Nitrogenized Nutrition.

Of Bone: The Skeleton.—Structure and Chemical Composition of Bone.—Sources of its Constituents.—The Process of Ossification.—Experiments on the Growth of Bone.—Influence of Physical Agents on Development and Nutrition .... Page 243

CHAPTER XIV.

OF THE NERVOUS SYSTEM.

Divisions of the Nervous System.—Cerebro-spinal and Sympathetic.—Fibrous and Vesicular.
Structure and Functions of Nerve Fibres.—Centripetal and Centrifugal.—Rate of Conductibility.
Anatomical Examination of the Structure and Functions of Nerve Vesicles.—They diffuse Influences, are Magazines of Force.—Element of Time introduced by Registering Ganglia.—Oxidation necessary to Nerve Activity.—Necessity of Repair and Rest.—Electrical Examination of the Functions of Vesicles.—Anatomical and Electrical Examinations agree.
Automatic Nerve Arc.—Cellated Nerve Arc.—Multiple Arcs.—Commissures.—Registering Nerve Arcs.—Sensorium.—Influential Arc.
Suggestions derived from cerebral Structure respecting the Soul.—Its independent Existence and Immortality.
Ideas of Time and Space.—Objective, subjective, and impersonal Operations.—Vestiges of Impressions and their Interpretation.—Finite Nature of Knowledge.—Mental Emotions 258

CHAPTER XV.

THE SPINAL AXIS.

Primitive Development of Nervous System.—Its final Condition in different Vertebrates.
The Spinal Cord: its Structure.—Its Membranes.—Its Thirty-one Pairs of Nerves.—Properties of their Roots.—Functions of the Cord.—Bell's Discovery.—Transmission of Longitudinal and Transverse Influences.—Reflex Action of the Cord.—Nature of Reflex Action.—Motor and Sensory Tracts of the Cord.—Summary of its Functions.
The Medulla Oblongata: its Structure and Functions.
The Pons Varolii: its Structure and Functions.
Dr. Carpenter's Views of the Analogy between the Spinal Cord of Vertebrates and the Ventral Cord of Articulates 291

CHAPTER XVI.

OF THE BRAIN.

The Brain: its Structure.—Its Motor and Sensory Parts, Hemispheres, and Commissures.—The Sensorium.—Variations of the Hemispheres in Size and Weight.—Instrumental Nature of Cerebrum.—The Cerebellum: its Structure and Functions.—Co-ordinates muscular Motions.—Connection with Amativeness.—Phrenology.—Conditions of Action of Brain.
Symmetrical Doubleness of the Brain.—Function of each Half, and of both conjointly.—Independence and Insubordination of each Hemisphere.—Double Thought.—Alternate Thought.—Sentiment of Pre-existence.—Loss of Perception of Time 313

CHAPTER XVII.

OF THE CRANIAL NERVES AND THE GREAT SYMPATHETIC.

Enumeration of the Cranial Nerves.—The Third Pair, or Oculo-motor.—The Fourth Pair, or Pathetici.—The Fifth Pair, or Trigemini.—The Sixth Pair, or Abducentes.—Illustrations of the Third, Fourth, Fifth, and Sixth Pairs.—The Seventh Pair, or Facial.—Illustration of the Facial.—The Ninth Pair, or Glosso-pharyngeal.—Illustration of the Glosso-pharyngeal.—The Tenth Pair, or Pneumogastric.—Illustration of the Pneumogastric.—Illustration of the Laryngeals.—The Eleventh Pair, or Spinal Accessory.—The Twelfth Pair, or Hypoglossal.—Illustration of the Hypoglossal.
The Phrenic Nerve.
Of the Great Sympathetic System.—Position, Structure, and Origin of the Sympathetic.—Its Relation with the Pneumogastric.—Its Connection with the Spinal System.—Its Plexuses.—Its

Ganglia.—They are Reservoirs of Force.—Summary of the Functions of the Sympathetic.—Illustration of the Sympathetic.—The Abdominal Plexuses.—The Solar Plexus.—The Mesenteric Plexuses........ Page 333

CHAPTER XVIII.

OF THE VOICE.

Origin of the Voice.—Comparative Physiology of Noise, Song, Voice.—Distinction between Song and Speech.—The Larynx, and its Action in Singing.—Müller's Explanation of the Action of the Vocal Organs.—Speaking Animals and Machines.

Nature of Words and their constituent Sounds.—Vowels and Consonants.—Whispering.—Use of the Voice of Animals.

Of Languages: their Duration, Character, History.—Registry of Sounds by Writing and Printing.—Musical Signs.—Alphabetic Writing........ 351

CHAPTER XIX.

OF HEARING.

The Senses: General Remarks upon.—Five Organs of Sense.—Necessity of Apparatus for the Appreciation of Time, Space, Pressure, Temperature, and Chemical Qualities.

Of Hearing.—General Structure of the Organ of Hearing.—Physical Peculiarities of Sounds, Intensity, Time of Vibration, and Quality.—The Tympanum, Cochlea, and Semicircular Canals are for the Appreciation of these peculiarities.

Structure and Functions of the Tympanum, or Measurement of Intensity.

Structure of the Cochlea, its Spiral Lamina and Scalæ.—Measures the Time of Vibration.—Accomplishment of Interference in the Scalæ.—Comparative Anatomy of the Cochlea.

Structure of the Semicircular Canals.—They estimate the Quality of Sounds.

Comparative Anatomy of the Auditory Mechanism.—Its Progress in Development.—Imperfection of the Doctrine of Means and Ends........ 359

CHAPTER XX.

OF VISION.

Analogy between Sound and Light.—Comparative Anatomy of Vision.—Perception of Warmth.—Structure of Ocelli.—Use of Lenses.—Physical Principle of the Organ of Vision.

Description of the Human Eye.—Optical Action of its Parts.—Spherical and Chromatic Aberration.—Receiving Screen of the Eye is the black Pigment.—Long and short Sight, and their Correction.—Limits of Vision are included in one Octave.—Limit in estimating the Brightness of Light.

Nervous Mechanism of the Eye: its Structure and Functions.—Manner of Perception by the Retina.—The black Pigment absorbs the Rays.—Single and double Vision.—Duration of Impressions.—Ocular Spectra.—Erect Vision.—Idea of the Solidity of Bodies.—Hypothesis of the Action of the Retina.

Accessory Apparatus of the Eye.—The Eyebrows.—Eyelids.—Lachrymal Apparatus.—Muscles of the Ball........ 379

CHAPTER XXI.

OF CEREBRAL SIGHT OR INVERSE VISION.

Difference between ordinary Vision and cerebral Sight.—Inverse Vision depends on the Vestiges of Impressions existing in the Brain.

Condition of our perceiving these Impressions is that they must be equal in Intensity to present Sensations.—Two Methods of accomplishing this Equalization: 1st, by re-enforcing the old Impressions; 2d, by diminishing the present Sensations.

Emergence of old Impressions in Sleep, Fever, Death.—Artificial Emergence of such Vestiges by Protoxide of Nitrogen, Opium, etc.

Cerebral Sight used teleologically to indicate the Immortality of the Soul........ 401

CHAPTER XXII.

OF TOUCH, AND THE DETERMINATION OF PRESSURES AND TEMPERATURES.

Functions of the tactile Mechanism: its Structure.—Regions of different Sensitiveness.—Comparative Physiology of Touch.—Estimate of physical Qualities.
Perception of Temperature.—Subjective Sensations of Temperature........................Page 417

CHAPTER XXIII.

OF SMELLING, AND THE MEANS OF DISTINGUISHING GASEOUS AND VAPOROUS SUBSTANCES.

Structure of the Organ of Smell.—Its proper Instrument the First Pair of Nerves.—Limited Region of Smell.—Conditions of its perfect Action.—Duration of Odors.—Their Localization.—Subjective Odors........ 423

CHAPTER XXIV.

OF TASTE.

Conditions for Taste.—Structure and Functions of the Tongue.—Tactile and Gustative Regions of the Tongue.—Complementary Tastes.—Subjective Tastes........ 427

CHAPTER XXV.

OF ANIMAL MOTION.

Ciliary and Muscular Motion.—Description of Cilia and the Manner of Action.
Muscular Fibre: its Forms, Non-striated and Striated.—Muscle Juice.—Manner of Contraction of a Muscle: its supply of Blood-vessels and Nerves.—Its Chemical Change during Activity.—Its Rise of Temperature.—Effect of Electrical Currents.—Duration of Contractility.
Doctrine that Muscle Contraction is the result of Muscle Disintegration.—Manner in which ordinary Cohesion is brought into play.—Manner of Restoration.—Removal of the Heat and Oxidized Bodies.
Rigor Mortis.—Connection of Muscle for Locomotion.—Of Standing.—Walking.—Running. 431

BOOK II.

DYNAMICAL PHYSIOLOGY.

COURSE OF LIFE.

CHAPTER I.

OF THE PRINCIPLE OF ORGANIZATION, OR PLASTIC POWER.

Remarks on the Subdivision of Physiology.
Career of an Organic Form.—Three Modes of Development.
Inquiry respecting the special Principle of Organization.—Illustration from the Growth of a Plant in Darkness and Light.—Inference respecting Plastic Power: its Nature and Properties.—Of the ordinary Growth of a Plant, and the Sources from which its Materials are derived.
Relation of all Organisms to each other.
Correction of the Doctrine of a Plastic Power, from Considerations regarding the Individuality of a Plant.—Plants are Operations, not Individuals.—Physical Illustration of this View.
Conclusion respecting the Nature of the Plastic Power: that it is a continued Manifestation of an antecedent physical Impression........ 455

CHAPTER II.

OF THE INFLUENCE OF PHYSICAL AGENTS ON THE ORGANIC SERIES.

Of the Geography of Plants: their horizontal and vertical Localization.—Influence of Heat on organic Distribution: isotheral and isochimenal Conditions.—Effects of Variations in the Density of the Air, Moisture, Soil, Sunlight, Length of Day.—Definite Quantity of Heat required by Plants.

Secular Perturbations in the Species of Plants.—Long Periods of Time required.—Secular geological Changes.

Inverse Problem of the Investigation of the Earth's History from her fossil Flora.—Two great terrestrial Epochs: Change in the Constitution of the Air, and Localization of Organisms through Decline of the Earth's Interior Heat.

Difference between abrupt and gradual Impressions.—Invariable Causes may produce abrupt Crises.

Extension of the above Principles to the Case of Animals.—Case of the Inca Indians.

General Argument supported by the Extinction of Forms.—Development is under the Influence of Law.—Rudimentary Organs and Excesses of Development.—The Idea of Development by Law consistent with natural Facts..........Page 472

CHAPTER III.

OF THE ORGANIC CELL: ITS DEVELOPMENT, REPRODUCTION, AND DIFFERENTIATION OF STRUCTURE AND FUNCTION.

Simple and Nucleated Cells.—The Simple Cell: its Parts and Functions.—The Nucleated Cell: its Parts and Functions.—Activity of the Nucleus.—Other Forms of Cells.—Cells arise by Self-origination and Reproduction.—Reproduction by Subdivision and Endogenously.

The Animal Cell.—Forms of Cellular Tissue.—Forms of Vascular Tissue.—Spiral Vessels, Ducts, etc.

Differentiation of Cells.—Acquisition of new Functions.—Differentiation of the Animal Cell.—Depends on Physical Causes.—Influence of Heat and Air.—Epoch of Differentiation.... 492

CHAPTER IV.

OF REPRODUCTION AND DEVELOPMENT.

Relation of Organic Beings: they come from a similar Cell and develop to different Points.—Their Division by Classification is fictitious.—Development and Differentiation.—Homogenesis and Heterogenesis.—They depend on physical Conditions.—The reproductive State closes Development.

Development is from the General to the Special.—Law of Von Bar.—Invariable Sequence in Differentiation.

OF REPRODUCTION: 1*st. By Generation.—Conjugation and Filaments.—The Sperm-cell: its Production.—Spermatozoa.—The Germ-cell: its Production.*

Ovum in the Ovary.—Its Structure.—Corpus Luteum.

Ovum in the Oviduct.—Mulberry Mass.—Germinal Membrane.—The Chorion.

Ovum in the Uterus.—Membrana Decidua.—Placenta.—Development of the Embryo.—Types of Nutrition.—Of Conception.—Of Gestation.—Of Parturition.—Influence of both Parents.

2*d. By Gemmation.—Budding of Plants and Animals.—Of Grafting.—Limit of Gemmation.—Influence of Temperature on Gemmation.*

Alternations of Generation.—Its Explanation.......... 505

CHAPTER V.

THE GROWTH OF MAN.

Infancy.—Weight and Size of the Infant.—Weight and Size at subsequent Periods.—Development of the Intellect.—Maturity of Man.—Tendency to Crime.—Maxima of Physical and Mental Strength.

Mental and Physical Decline.—Mortality at different Periods of Life.—Comparative Structure, Functions, and Mortality of the two Sexes.
Artificial Epochs of Life.—Gradual Change in the Mental Qualities.—Independent Existence of the Soul. .... Page 538

CHAPTER VI.

OF SLEEP AND DEATH.

Causes of the Necessity for Sleep.—Its Duration and Manner of Approach.—Manner of Awaking.—Cause of Night-sleep.—Increased Warmth required.—Connection of Sleep and Food.
Of Dreams: their Origin and Phenomena.—Somnambulism.—Nightmare.
Of Death.—Old Age.—Internal Causes of Decline.—Death by Accident and by Old Age.—The Hippocratic Face.—Final Insensibility 551

CHAPTER VII.

ON THE INFLUENCE OF PHYSICAL AGENTS ON THE ASPECT AND FORM OF MAN AND ON HIS INTELLECTUAL QUALITIES.

Differences in Form, Habits, and Color of Men.—Ideal Type of Man.—Its Ascent and Descent.—Causes of these Variations.
Doctrine of the Unity of the Human Race.—Doctrine of its Origin from many Centres.
Influence of Heat on Complexion.—Cause of Climate Variations.—Influence of Heat illustrated by the cases of the Indo-Europeans, the Mongols, the American Indians, and the Africans.—Distribution of Complexion in the Tropical Races.
Variations in the Skeleton.—Four Modes of examining the Skull.—Connection of the Shape of the Skull and Manner of Life.—Physical Causes of Variation of the Skull.
Influence of the Action of the Liver on Complexion.—Influence of the Action of the Liver on the Form of the Skull.—Base Form of Skull arising from Low as well as High Temperatures.—Disappearance of the Red-haired and Blue-eyed Men in Europe.
The Intellectual Qualities of Nations.—Synthetical Mind of the Asiatic.—Analytical Mind of the European.—Their respective Contributions to Human Civilization.—Spread of Mohammedanism in Africa.—Spread of Christianity in America.—Manner of the Progress of all Nations in Civilization 563

CHAPTER VIII.

SOCIAL MECHANICS.

Comparative Sociology.—Connection of Structure and Habit.—Connection of History and Physiology.—Insect Society.—Descartes's Doctrine that Insects are Automata.—Necessity of a Mechanism of Registry for Instinct, Reason, and Civilization.
Nature of Man.—Influence of surrounding Circumstances on him.—Definiteness of his Career.
GENERAL FACTS OF EUROPEAN HISTORY.—*Introduction of Egyptian Civilization into Europe.—The Registry of Facts by Writing.—Egyptian Philosophy in the Greek Schools.—The Persian Empire: its Influence.—Analytical Quality of the European Mind.—Influence of the Greek Schools on modern Philosophy.*
Origin of European Commerce.—Discovery of the Straits of Gibraltar.—Macedonian Campaign.—Reconstruction of Monarchy in Egypt.
The Roman Empire: its centralizing and civilizing Power.—Fall of European Paganism.—Influence of the Christian Church.—The Sabbath Day.—The Reformation.
Influence of Mohammedanism on Europe.—The Arab physical Science.—The Crusades.—Discovery of America by the Spaniards.—Fall of the Spanish Power.
Later Mental Changes in Europe.—Disappearance of Credulity.—Physiological Change of Europeans.—Effect of Mohammedanism in changing the Centre of Intellect of Europe.—Analytical Tendency of the European Mind.—Advantages resulting therefrom 602

LIST OF ILLUSTRATIONS.

FIG.			PAGE
1.	The lower Jaw	Wilson	41
2.	Section of Stomach	Author	42
3.	Digestive Tract	Harrison	48
4.	Mucous Membrane of Stomach	Wilson	50
5.	Stomach Follicles and Tubes	Todd and Bowman	50
6.	Section of Stomach Tubes	" "	51
7.	The Hydra		51
8.	Digestive Tract of Beetle	Milne Edwards	58
9.	Mucous Membrane of Beetle's Stomach	Photograph by Author	58
10.	Digestive Tract of Fowl	" "	58
11.	Stomach of African Ostrich	Cuvier	59
12.	" of Dormouse	"	59
13.	" of Cape Hyrax	"	59
14.	" of Porcupine	"	59
15.	" of Porpoise	"	59
16.	" of Kangaroo	"	59
17.	" of a Ruminant	"	59
18.	Posterior View of human Stomach	Retzius	61
19.	Posterior View of Duodenum	Bourgery	68
20.	Diagram of Brunner's Glands	Author	69
21.	Diagram of Follicles of Lieberkuhn	"	69
22.	Peyerian Glands	Thomson	70
23.	Section of Ileum Wall	Kolliker	85
24.	Villi of Monkey	Camera Lucida by Author	85
25.	Villi of Duodenum	Author	85
26.	Villi of Jejunum	"	85
27.	Section of Villi	"	86
28.	Villi of Squirrel	"	88
29.	Principle of Venturi	"	90
30.	Thoracic Duct	Wilson	90
31.	Chyle Corpuscles with Blood-cells	Photograph by Author	93
32.	" " " Water	Author	94
33.	" " " Acetic Acid	"	94
34.	Lymphatics of large Intestine	Bourgery	97
35.	Diagram of Lymph Gland	Goodsir	97
36.	Evolution of Lymph Cells	"	97
37.	Capillary Depression of a Liquid	Author	104
38.	Capillary Elevation of a Liquid	"	104
39.	Passage of Water through a Crevice	"	105
40.	Endosmometer	"	106
41.	Selecting Power of a Membrane	"	108
42.	Human Blood-cells	Photograph by Author	116
43.	Elliptic Blood-cells	" "	116
44.	Action of Water on elliptic Cells	" "	116
45.	Action of Acetic Acid	" "	117
46.	Reptile Blood-cells	" "	117
47.	Human Blood-crystals	Lehmann	119

FIG.			PAGE
48.	Blood-crystals of Guinea-pig	Lehmann	119
49.	Blood-crystals of Squirrel	"	120
50.	Stellated Blood-cells	Photograph by Author	127
51.	Capillary Motion	Author	131
52.	Motion in Cells	"	132
53.	Circulation in Tradescantia	"	132
54.	Diagram of Fish Circulation	Milne Edwards	135
55.	Rudimentary Heart	Thomson	135
56.	Diagram of single Heart	Roget	136
57.	Heart of Dugong	Home	136
58.	Human Heart on right Side	Wilson	136
59.	Human Heart on left Side	"	137
60.	Muscular Fibres of Heart	Author	137
61.	Vessels of Mucous Membrane of Stomach	"	142
62.	Vessels of Villi of Duodenum	"	142
63.	Capillary Circulation of Frog's Foot	Wagner	142
64.	White Corpuscles in the still Layer	"	143
65.	Valves of Veins open	Roget	143
66.	Valves of Veins shut	"	143
67.	Diffusion of Gases	Author	152
68.	Diffusion through Earthenware	"	152
69.	Diffusion through India-rubber	"	153
70.	Passage through Films	"	153
71.	Force of Filtration	"	155
72.	Air Vesicles of Insect	Fabricius	157
73.	Spiracle of Insect	Photograph by Author	157
74.	Air Sac of Fish	Blasius	157
75.	Lung of Reptile	Flourens	158
76.	Lungs of Frog	"	159
77.	Human Air-tubes	Wagner	160
78.	Heart and Lungs	"	160
79.	Capillaries on Lungs	Rathke	160
80.	Mechanism of Respiration	Author	161
81.	Experiments on Respiration	Regnault and Reiset	170
82.	Hepatic Cœcum of Cray-fish	Leidy	198
83.	Bile-ducts entering the Duodenum	Paxton	199
84.	Hepatic Veins in the Lobules of the Liver.	Kiernan	199
85.	Origin of Hepatic Veins	"	200
86.	Origin of Bile-ducts	"	200
87.	Hepatic Cells	"	201
88.	Section of Kidney	Wilson	215
89.	Diagram of Malpighian Corpuscle	Kolliker	216
90.	Glomerulus of horse	"	216
91.	Cilia on Uriniferous Tube	Bowman	216
92.	Diagram of Malpighian Circulation	"	217
93.	Malpighian Tuft	Isaacs	217
94.	Ruptured Malpighian Coil of Deer	"	217
95.	Nucleated Cells on Coil	"	217
96.	Development of Mammary Gland	Kolliker	225
97.	Section of human Mamma		225
98.	Colostral Corpuscles	Photograph by Author	225
99.	Epidermis of Dog	" "	235
100.	Section of Skin	Kolliker	235
101.	Under Surface of Cuticle	Todd and Bowman	235
102.	Papillæ of Palm	" "	235
103.	Skin of Palm	" "	236

FIG.			PAGE
104.	Section of Hair	Todd and Bowman	236
105.	Transverse Section of Hair	Photograph by Author	237
106.	Sudoriparous Gland	Wagner	237
107.	Fat-cell	Schwann	246
108.	Adipose and areolar Tissue	Berres	246
109.	Transverse Section of Bone	Photograph by Author	254
110.	Lucunæ and Canaliculi	Author	254
111.	Ossifying Cartilage	Kolliker	255
112.	Ossifying Cartilage	Photograph by Author	256
113.	Ossifying Femur	Kolliker	256
114.	Axis Cylinder	Author	261
115.	Subdivision of Nerve Fibres	Kolliker	262
116.	Nerve-cells	"	263
117.	Bipolar Nerve-cells	"	264
118.	Multipolar Nerve-cell	Author	264
119.	Nerve Cells and Tubes	Wagner	264
120.	Nerve Cells and Tubes	Purkinje	264
121.	Dorsal Ganglion of Mouse	Valentin	267
122.	Simple automatic Arc	Author	277
123.	Simple cellated Arc	"	278
124.	Multiple Nerve Arcs	"	278
125.	Commissured Arcs	"	279
126.	Nervous System of Larva of Sphinx Ligustri	Newport	279
127.	Nervous System of Pupa of Sphinx Ligustri	"	279
128.	Nervous System of Imago of Sphinx Ligustri	"	279
129.	Nervous System of Asterias	Tiedemann	279
130.	Nervous System of Patella	Cuvier	279
131.	Nervous System of Octopus	"	279
132.	Nervous System of Aplysia	"	280
133.	Registering Nerve Arc	Author	281
134.	Suppression of Centrifugal Branch	"	281
135.	Influential Arc	"	282
136.	Primitive Trace	Bischoff	293
137.	Origin of Brain on Spinal Cord	"	293
138.	Spinal Cord	Photograph from Leveillè	295
139.	Section of Spinal Cord	" " "	295
140.	Spinal Dura Mater	" " "	296
141.	Origin of anterior Roots of Nerves	" " "	297
142.	Origin of posterior Roots	" " "	297
143.	Origin of both Roots	" " "	297
144.	Portion of Cord of Spirostreptus	Newport	301
145.	Front of Medulla Oblongata	Photograph from Leveillè	305
146.	Back of Medulla Oblongata	" " "	305
147.	Interior of Medulla and Pons	" " "	305
148.	Posterior View of Medulla Oblongata	Todd and Bowman	306
149.	Nervous System of Larva of Sphinx Ligustri	Newport	308
150.	Ganglion of Polydesmus Maculatus	"	309
151.	Ganglion of Centipede	"	312
152.	Thoracic Portion of Cord of Sphinx Ligustri	"	313
153.	Respiratory and locomotive Ganglia	"	313
154.	External lateral Face of Brain	Photograph from Leveillè	316
155.	Superior Aspect of Brain	" " "	316
156.	Internal lateral Face of Brain	" " "	317
157.	Base of Brain	Photograph by Author	317
158.	Diagram of Brain	Mayo	318
159.	The Motor Tract	Bell	319

FIG.			PAGE
160.	The Sensory Tract	Bell	320
161.	Nerves of the Orbit	Photograph from Leveillè	334
162.	Nerves in the Orbital Cavity	" " "	335
163.	Diagram of the Fifth Nerve	" " "	335
164.	Ganglion of Gasser	" " "	335
165.	The Fifth Nerve	" " "	336
166.	The inferior Maxillary	" " "	336
167.	The Facial Nerve	" " "	337
168.	The Glosso-pharyngeal Nerve	" " "	339
169.	Diagram of Anastomoses	" " "	339
170.	The left Pneumogastric	" " "	341
171.	Pulmonary Ganglia	" " "	342
172.	The inferior Laryngeals	" " "	342
173.	The Hypoglossal Nerve	" " "	343
174.	The Phrenic Nerve	" " "	344
175.	Relation of the Sympathetic and Spinal	Todd and Bowman	345
176.	The Great Sympathetic	Photograph from Leveillè	348
177.	Abdominal Plexuses	" " "	349
178.	The Solar Plexus	" " "	350
179.	The Mesenteric Plexuses	" " "	350
180.	Spiracle of Insect	Photograph by Author	352
181.	Profile of Larynx	Leveillè	354
182.	Posterior View of Larynx	"	354
183.	External, middle, and internal Ear	"	362
184.	Tympanic Cavity	"	362
185.	Facial in the Aqueduct of Fallopius	"	362
186.	Interior of Cochlea	"	369
187.	Section of Cochlea	"	369
188.	Magnified Section of Cochlea	"	370
189.	Cochlear Nerve	"	370
190.	Auditory Nerve	"	370
191.	Ossicles and their Muscles	"	370
192.	Tympanic Face of Labyrinth	"	374
193.	Cranial Face of Labyrinth	"	374
194.	Interior of Labyrinth	"	375
195.	Interior of Labyrinth	"	375
196.	Profile of Eye	"	383
197.	Front View of Eye	"	383
198.	Section of Eye	"	383
199.	Veins of the Choroid	"	385
200.	Arteries of the Choroid	"	385
201.	Yellow Spot of Soemmering	Soemmering	385
202.	Membrane of Jacob	Jacob	390
203.	Simple Papillæ	Todd and Bowman	420
204.	Compound Papillæ	Kolliker	420
205.	Olfactory Nerve	Leveillè	424
206.	Olfactory Nerve	"	424
207.	The Tongue	Photograph from Leveillè	428
208.	Ciliated Cells	Author	431
209.	Ciliated Animalcule	Ehrenberg	432
210.	Hydra walking	Trembley	432
211.	Striated muscular Fasciculi	Photograph by Author	433
212.	Human Sarcolemma	Bowman	433
213.	Sarcolemma of Fish	"	433
214.	Ultimate muscular Fibre	Photograph by Author	433
215.	Unstriped muscular Fibre	Author	435

FIG.			PAGE
216.	Unstriped Fibres in Acetic Acid	Author	435
217.	Muscle Cells	Kolliker	435
218.	Muscular Fasciculi torn in Discs	Bowman	436
219.	Transverse Section of human Muscle	"	437
220.	Transverse Section of Muscle of Teal	"	437
221.	Non-fibrillated Insect Fasciculi	Photograph by Author	437
222.	Non-fibrillated Insect Fasciculi	" "	437
223.	Contracting Muscle of Dytiscus	Bowman	438
224.	Sarcolemma raised in Bullæ	Todd and Bowman	438
225.	Fasciculus contracting	" "	439
226.	Distribution of muscular Capillaries	Berres	439
227.	Muscular Arteries and Veins	Kolliker	440
228.	Distribution of muscular Nerves	Burdach	440
229.	Volume of contracting Muscle	Author	450
230.	Hæmatococcus Binalis	Hassall	494
231.	Conferva glomerata	Mohl	495
232.	Simple Cellular Tissue	Photograph by Author	497
233.	Muriform Cellular Tissue	" "	497
234.	Fibro-cellular Tissue	" "	497
235.	Spiral Vessels of Cactus	" "	498
236.	Spiral Vessels of Banana	" "	498
237.	Woody Fibre of Pine	" "	498
238.	Yellow Fibrous Tissue	Author	499
239.	White Fibrous Tissue	"	499
240.	Areolar Tissue	"	499
241.	Development of Frog	Rusconi	509
242.	Frog		510
243.	Development of Crab	Couch	510
244.	Development of Insects	Straus Durckheim	510
245.	Zygnema Quininum	Kützing	515
246.	Testis	Arnold	517
247.	Development of Spermatozoa	Wagner	518
248.	Section of Ovary	Kolliker	521
249.	Section of Graafian Vesicle	Von Bär	521
250.	Ovum	Barry	521
251.	Diagram of Graafian Vesicle	Kirkes and Paget	521
252.	Corpora Lutea	Patterson and Montgomery	522
253.	Ovarian Ovum		523
254.	Ovarian Ovum		523
255.	Segmentation of Ovum	Bischoff	524
256.	Segmentation of Ovum	Kolliker and Bagg	524
257.	Uterine Tubes	Weber	525
258.	Layers of Germinal Membrane	Bischoff	527
259.	Primitive Groove	"	527
260.	Origin of Brain	"	528
261.	Production of Vessels	Wagner	529
262.	Production of Lymphatics	Kolliker	529
263.	Rudimentary Heart	Thomson	529
264.	Fœtal Heart	Von Bär	530
265.	Hydra budding	Trembley	534
266.	Newton	Photograph from Principia	563
267.	Australian	D'Urville.—Photographed from Prichard	563
268.	Australians	D'Urville.— " " "	564
269.	Brahmin	Branwhite.— " " "	573
270.	Chinese	" " "	574
271.	Kamtschatdale	" " "	575

FIG.			PAGE
272.	Sac Indian	Catlin.—Photographed from Prichard	575
273.	Cherokee Indian	Catlin.— " " "	576
274.	California Indian	Choris.— " " "	576
275.	California Indians	Choris.— " " "	576
276.	Abyssinian	D'Abbadie.— " " "	577
277.	Native of Madagascar	" " "	577
278.	Native of Mozambique	" " "	578
279.	Negro of Guinea	Author	579
280.	Philippine Negro	Choris.—Photographed from Prichard	579
281.	Skeleton of Man, Chimpanzee, and Orang	Photograph by Author	581
282.	Skull of European	Prichard	582
283.	Skull of Negro	"	582
284.	Skull of Chimpanzee	"	582
285.	Skull of Orang	"	582
286.	Caucasian Skull	"	583
287.	Mongol Skull	"	583
288.	Negro Skull	"	584
289.	Titicacan Skull	"	584
290.	Base of human Skull	"	584
291.	Base of Orang Skull	"	584
292.	Esquimaux Skull	"	585
293.	Negro Skull	Author	587
294.	French Skull	"	587
295.	Cephalic Ganglia	Newport	607
296.	Thoracic Portion of Ventral Cord	"	607

HUMAN PHYSIOLOGY,

STATICAL AND DYNAMICAL.

HUMAN PHYSIOLOGY.

BOOK FIRST.

STATICAL PHYSIOLOGY.

CONDITIONS OF LIFE.

CHAPTER I.

Conditions of Life.—Nature and Sources of Substances supplied to the Body.—Annual Quantities required.—Table of Physiological Standards.—Animals do not create, but transform Substances.—Properties and Quantities of Matters received by the System.—Properties and Quantities of those it restores.—Heat of the Body arises from Combustion.—Cooling Agencies in an Animal.—Necessity of Repairs in the System.—Physical Aspect of Man.—The Soul.—The Vital Principle.—Importance of Physical Science to Physiology.

For the maintenance of the life of man three chemical conditions must be complied with. He must be furnished with air, water, and combustible matter.

Under the same conditions, also, all animals exist. Even in those which seem to furnish us with instances of departure from this general rule, the exceptions are rather apparent than real. To breathe, to drink, to eat, are the indispensable requisites of life. If there be among insects some which seem never to take water, or among fishes some which never taste solid food, these peculiarities disappear as soon as we understand them properly. Where a high development has been attained, as in man, experience assures us that the same inevitable result awaits a cessation of respiration for a few moments, an abstinence from water for a few hours, or from food for a few days.

Three conditions of life.

The supply of a part of these necessaries of life is adjusted to the urgency of the want. The act of breathing is incapable of delay, but the air is accordingly every where present, and always fit for use. We can bear with thirst for a little time, and the earth here and there furnishes her springs and other stores of water. But far otherwise is it in the obtaining of food. It is the lot of all animals to secure nourishment by labor, and even of men the larger proportion, both

Sources of supply of material.

in civilized and savage countries, submit to a hard destiny. To obtain their daily bread is the great object of life.

What is the philosophical explanation of this necessity for a supply of air, of water, of food? Why is it that the system will bear so little delay?

Life depends on destruction of material.

The answer which Physiology gives to these questions is an answer of ominous import, but the whole science is a commentary on its truth. The condition of life is death. No part of a living mechanism can act without wearing away, and for the continuance of its functions there is therefore an absolute necessity for repair.

It has been greatly to the detriment of physiology and the practice of medicine that this conception has not been thoroughly realized until late times. The aspect of identity which an animal presents is an illusion, hiding from us the true state of the case. It has been the fruitful source of errors which have retarded the progress of these sciences. What could their career possibly be when men had persuaded themselves that a living being possesses a capacity for resisting any change, and that organic structures never yield to external physical influences until after death?

But life, far from being a condition of immobility, is a condition of ceaseless change. An organism, no matter of what grade it may be, is only a temporary form, which myriads of particles, passing through a determinate career, give rise to. It is like the flame of a lamp, which presents for a long time the same aspect, being ceaselessly fed as it ceaselessly wastes away. But we never permit ourselves to be deceived by the simulated unchangeableness which such a natural appearance offers. We recognize it as only a form arising from the course which the disappearing particles take. And so it is even with man. He is fed with more than a ton weight of material in a year, and in the same time wastes more than a ton away.

Conditions of equilibrium in man.

There is, therefore, a general condition of equilibrium which every animal presents, depending upon its receipts and its wastes, a proper knowledge of the conditions of which is at the foundation of Physiology. That we may approach this problem under its simplest form, free it from all unnecessary complications, and make it of most interest to the special object of this book, the remarks now to be made will be confined to our own species, and, except when otherwise stated, to a condition of health, and to the adult period of life.

To have a uniform standard of reference, we may assume one hundred and forty pounds as the weight of an adult healthy man. Now the constant consumption of food, water, and atmospheric air tends steadily to increase that weight, and even in a very short time a disturbance arising from these sources would be perceptible, were there not some causes of

compensation. But even after a year, if a state of health is maintained, the weight may remain precisely what it was, and this may continue year after year in succession. The consumption of large quantities of solid, liquid, and gaseous matter does not therefore necessarily add to the weight.

There are two periods of life for which this observation will not hold good. They are infancy and old age. During the former the weight increases from day to day, and during the latter it slowly declines.

If there be thus causes for the increase of weight of the living system, there are also causes for its diminution. Setting aside the minor ones, these may be chiefly enumerated as loss by urine, by fæces, by transpired and expired matters. By transpired matters, are meant such as escape under the form of liquids and gases from the skin, and by expired matters, vapors and gases escaping from the lungs. There is, therefore, a tendency to an increase and a tendency to a diminution of the weight, and, in the condition of equilibrium we are considering, these must balance one another.

If a man of the standard weight abstains from the taking of water and food, a good balance will prove that in the course of less than an hour he has become lighter. If he still persists, it needs no instrument to detect what is going on; the eye perceives it, for emaciation ensues.

How, then, is it possible for a living being to continue at its standard, except the causes of increase are precisely equal in effect to the causes of diminution? Overlooking minor ones, we may therefore assert that the sum total of food, water, and atmospheric air taken in a given period of time is precisely equal to the sum total of all the losses by urine, fæces, transpired, and expired matters; for if the receipts were greater, the weight must increase—if the losses were greater, the weight must diminish. Persistency in this respect proves equality, and the case is just as simple as in the common affairs of life; he who pays less than he receives grows rich; if his payments are more than his receipts, he becomes poor; but his condition is unchanged if his payments and receipts are equal. Infancy, old age, and manhood answer to these circumstances respectively.

Quantity of matter required by man in a year.

From the army and navy diet scales of France and England, which of course are based upon the recognized necessities of large numbers of men in active life, it is inferred that about $2\frac{1}{4}$ pounds avoirdupois of dry food per day are required for each individual; of this about three quarters are vegetable and the rest animal. At the close of an entire year the amount is upward of 800 pounds. Enumerating under the title of water all the various drinks—coffee, tea, alcohol, wine, &c.—its estimated quantity is about 1500 pounds per annum. That for oxygen may be taken at 800 pounds.

With these figures before us, we are able to see how the case stands. The food, water, and air which a man receives amount in the aggregate to more than 3000 pounds a year; that is, to about a ton and a half, or to more than twenty times his weight. This enormous mass may well attract our attention to the expenditure of material which is required for supporting life. It reveals to us the fact that the old physiological doctrine, that a living being is not influenced by external agents, is altogether a fallacy. A living being is the result and representative of change on a prodigious scale.

The condition of equilibrium which has just been set forth, moreover, leads to the conclusion that the aggregate weight of urine, fæces, transpired, and expired matter is the same for the same period of time. In round numbers, we may take it at a ton and a half.

Quantity of matter yielded by man in a year.

It can not be questioned that the materials which are rendered back to the external world, after having subserved the purpose of the animal and passed through its system, are compounds of those which were originally received as food, drink, and air, though they may have assumed in their course other, and perhaps, in our estimation, viler forms. Recognizing as indisputable the physical fact that not an atom can be created any more than it can be destroyed, we should expect to discover in the substances thus dismissed from the system every particle that had been taken in.

What, then, is man? Is he not a form, as is the flame of a lamp, the temporary result and representative of myriads of atoms that are fast passing through states of change—a mechanism, the parts of which are unceasingly taken asunder and as unceasingly replaced? The appearance of corporeal identity he presents year after year is only an illusion. He begins to die the moment he begins to breathe. One particle after another is removed away, interstitial death occurring even in the inmost recesses of the body.

From these general considerations we infer that the essential condition of life is waste of the body; and this not only of the body in the aggregate, but even of each of its particular parts. Whatever part it may be that is exercised is wearing away, and wherever there is activity there is death. And since parts that are dead are useless, or even injurious to the economy, the necessities simultaneously arise for their removal and for repair. Much of the complicated mechanism of animal structures is for the accomplishment of this double duty.

Great extent of the changes in the system of man.

For an organic being to live, its parts must die. The amount of activity it displays is measured by the amount of death, and in this regard every member of the animal series stands on the same level. Here, at

the very outset of our science, we must dismiss the vulgar error that the physical conditions of existence vary in different tribes, and that man is not to be compared with lower forms. We must steadily keep in view the interconnection of all, a doctrine which is the guiding light of modern physiology, and which authorizes us to appeal to the structure and functions of one animal for an explanation of the structure and functions of another. The more steadily we keep before us this philosophical conception of the interconnection of all organic forms, the clearer will be our physiological views. There has never been created such a thing as an isolated living being.

Necessity and uses of fixed physiological standards.

From the manner in which these general considerations of the mechanical and chemical equilibrium of the system of man have been introduced, it will doubtless be seen that it is the first business of the physiologist to disentangle the variable results which that system presents, as far as may be possible, and offer them under a standard estimate; that at the basis of this science there should be a table setting forth with the utmost exactness all the quantities concerned in such a standard type. Thus, assuming the weight of an adult man at 140 pounds, as we have done, it should show the diurnal consumption of combustible matter or food, of water, of air—the diurnal loss by evaporation, by secretion, by respiration. In contrast with this it should also give the nocturnal. It should also represent the quantity of bile, of saliva, of pancreatic juice; the weight of each one of the various salts and organic bodies they contain, the diurnal and nocturnal production of heat, &c.

For the purpose of the practice of medicine, a standard of 140 pounds will perhaps be found most convenient, but in a scientific point of view, and especially for comparative physiology, a standard of 1000 parts is best assumed. I now present an attempt at the construction of such tables, it being perhaps scarcely necessary to apologize for their extreme imperfection. Though offering the results at present received as most trustworthy, a very superficial examination will show how full they are of errors and contradictions. Perhaps it would not be too much to say that it will require the labor of many physicians, continued for centuries, to bring such tables to the truth. Yet the approach to precision in these hypothetical constants will in all times be a measure of the exactness of physiology, and it may be added, also, of the practice of medicine. The time is at hand when such a typical standard must be the starting-point for pathology, and no rational practice can exist without it. The passage of physiology, from a speculative to a positive science, is the signal for a revolution in the practice of medicine.

Moreover, physiology should furnish formulas for the computation of variations in these tabular numbers under variable conditions; as, for in-

stance, under low and high aerial temperatures, change of atmospheric pressures, absolute quiescence, or the near approach thereto, the effect of a determined amount of locomotion, or other muscular exertion, &c. As the science becomes more perfect, it should likewise attempt to embrace pathological states; as, for instance, the diurnal or periodic production of heat in fevers, the effect of the hygienic system of the bedroom.

Physiology having attained to this high condition, the practice of medicine in its great department of diagnosis will consist, in reality, in the solution of inverse problems. Given the variations from the standard existing in any case, to determine the cause of those variations. At this point diagnosis becomes a science, and ceases to be an art.

Illustration of the following table.

As in painting and statuary, the artist has an ideal model in his mind, a typical standard which no living being has perfectly reached, though some of the most beautiful may have approached thereto, so in physiology the standard or typical man presents the combined and mean values of all the human race.

A less comprehensive view presents us with distinct national standards, instead of this universal one, for every country has its own peculiarities. Results of the highest interest are to be perceived when these national standards are compared with one another. Even the same nation must offer, from age to age, modifications in its type expressive of the secular perturbations it is undergoing, as it advances or descends in a knowledge of the arts of life and civilization.

Moreover, there are typical standards of a still lower order, having reference to the conditions of sex and the period of life. Of these six may be designated—the infant, the adult, the aged, of the male and female sex respectively.

As illustrations of these remarks, and examples of the determination of the fundamental element of such a general physiological table, the standard weight of the body, we may take the following estimates. An examination of 20,000 infants, at the Maternité in Paris, gives for the weight of the new-born $6\frac{1}{4}$lbs.; the same mean value obtains for the city of Brussels. For about a week after birth this weight undergoes an actual diminution, owing to the tissue destruction which ensues through the establishment of aerial respiration, and which for the time exceeds the gain from nutrition. For the same age the male infant is heavier than the female, but this difference gradually diminishes, and at twelve years their weight is sensibly the same. Three years later, at the period of puberty, the weight is one half of what it is finally to be, when full development is reached. The maximum weight eventually attained is a little more than twenty times that at birth, this holding good for both sexes; but since the new-born female weighs less than the standard, and the new-born male more, the weight of the adult male is $136\frac{998}{1000}$ lbs., and of the

adult female $121\frac{201}{1000}$ lbs. The mean weight of a man, irrespective of his period of life, is $103\frac{720}{1000}$ lbs., and of a woman $93\frac{799}{1000}$ lbs. The mean weight of a human being, without reference either to age or sex, is $98\frac{759}{1000}$ lbs.

For the preceding numbers we are indebted to the researches of M. Quetelet, who likewise has in an interesting manner extended the methods of statistics to the illustration of the physical and moral career of man, and impressed us with the facts that in the discussion of the phenomena which masses present, individual peculiarity disappears and general laws emerge. The actions which seem to be the result of free will in the individual, assume the guise of necessity in the community. Just as we are sure that man is born, develops, and dies under the operation of laws that are absolutely invariable, so communities seem to be under the influence of unchangeable laws. "In communities man commits the same number of murders each year, and does it with the same weapons. We might enumerate beforehand how many individuals will imbrue their hands in the blood of their kind, how many will forge, how many poison, very nearly as we enumerate beforehand how many births and deaths will take place."

PHYSIOLOGICAL STANDARD TABLES.

Diurnal Ingesta, Secretions, and Excretions of a Man whose weight is 140 lbs. avoirdupois.

	Weight of body	140.000		
Ingesta.	Water	4.109		
	Oxygen	2.192		
	Dry vegetable food	1.687		
	Dry animal food	.563		
Secretions and Excretions.	Saliva	3.300		
	Gastric juice	14.080		
	Pancreatic juice	.440		
	Bile	3.500		
	Carbon from lungs	.500		
	Intestinal juice	.440		
	Loss of water by lungs	1.440		
	" " skin.	2.234		
	Fæces	.078		
	Urine	2.180, consisting of		
			Water	2.034
			Urea	.065
			Uric acid	.002
			Lactic acid	.037
			Sulphuric acid	.007
			Phosphoric acid	.008
			Chloride of sodium	.009
			Alkalies and earths	.016
			Other bodies	.002
In the Circulation.	Blood	17.000, consisting of		
			Water	13.328
			Albumen	1.190
			Fibrin	.037
			Discs	2.227
			Fats	.022
			Chloride of sodium	.061
			Chloride of potass	.006
			Phosphate of soda	.003
			Carbonate of soda	.012
			Sulphate of soda	.004
			Phos. lime and mag.	.004
			Oxide and phos. iron	.008
			Other bodies	.098

In this table the estimate is in the avoirdupois pound and decimals thereof.

Diurnal Ingesta, Secretions, and Excretions of a Man whose weight is 1000 parts.

	Weight of body	1000.000		
Ingesta.	Water	29.350		
	Oxygen	15.657		
	Dry vegetable food	12.050		
	Dry animal food	4.021		
Secretions and Excretions.	Saliva	23.576		
	Gastric juice	100.571		
	Pancreatic juice	3.143		
	Bile	25.000		
	Carbon from lungs	3.571		
	Intestinal juice	3.143		
	Loss of water by lungs	10.286		
	" " skin.	15.957		
	Fæces	.557		
	Urine	15.571, consisting of		
			Water	14.529
			Urea	.464
			Uric acid	.014
			Lactic acid	.264
			Sulphuric acid	.050
			Phosphoric acid	.057
			Chloride of sodium	.064
			Alkalies and earths	.114
			Other bodies	.014
In the Circulation.	Blood	121.429, consisting of		
			Water	95.200
			Albumen	8.500
			Fibrin	.264
			Discs	15.907
			Fats	.157
			Chloride of sodium	.436
			Chloride of potass	.043
			Phosphate of soda	.021
			Carbonate of soda	.086
			Sulphate of soda	.029
			Phos. lime and mag.	.029
			Oxide and phos. iron	.057
			Other bodies	.700

In this table the estimate is upon one thousand parts.

It is to be received as a doctrine admitting no controversy, that or-

ganic systems, whether vegetable or animal, whether humble or elaborately developed, possess no power of creating material. Their function is of necessity limited to the mere transformation of substances furnished to them. From this it follows, even in the case of man, that the substances dismissed from the system are metamorphosed forms of those which have been received, and that, whatever their appearance may be, they must have arisen from the reaction of the food, water, and air upon one another.

An animal creates nothing, but only transforms the substances it receives.

This reaction we may proceed to view as a purely chemical result; for, casting aside all the vain hypotheses of the older physiology, and permitting ourselves to be guided by the harmonies of nature, we should expect to recognize in the changes taking place in organic systems, and in the phenomena which attend those changes, the same results which arise in the artificial or experimental reaction of food, water, and air on each other. A very superficial examination of the facts shows at once the correctness of this expectation. On such an examination we now enter, premising it with some general remarks needful for our purpose on the nature and properties of food, water, and air.

The chemical properties of matters received.

1st. OF FOOD.—No article is suitable for food except it be of a combustible nature. Its chemical constitution must be such that if its temperature be raised to a proper degree with a due access of atmospheric air it will take fire and burn, and the products of its combustion must be carbonic acid gas and water, or those substances with nitrogen or its compounds.

2d. OF WATER.—This may be taken as the type and representative of all the various liquids used as drinks. It evaporates at any temperature, even at those which are lower than its freezing point, and in this evaporation produces cold. Water vaporizing from the skin absorbs 1114 degrees of heat, and hence exerts a most powerful refrigerating action. Over saline substances there are few bodies which exercise so general a solvent effect. In virtue of this property, it is enabled to introduce in the dissolved state such compounds as are wanted for the nutrition of the system, and in the same manner to carry away the wasted products of decay.

3d. OF ATMOSPHERIC AIR.—The active principle of the air is oxygen gas, the effects of which are moderated by the presence of a large quantity of nitrogen—four fifths of the air consisting of this latter substance. Physiologically, we often use the terms atmospheric air and oxygen synonymously.

The chief materials which a living being receives from the external world are, therefore, COMBUSTIBLE MATTER, WATER, OXYGEN GAS; and out of the action of these upon one another all the physical phenomena of its life arise.

Such being the nature and properties of the things received, we may now examine in the same general manner those which are dismissed from the system. Here, at the very outset, we encounter the important fact that they are oxidized or burned bodies.

Properties of substances dismissed by the system.

1st. As respects the urine and its constituents. Its liquid part, water, is an oxide of hydrogen, of which, though the greater portion may not have been produced in the economy, yet a certain quantity unquestionably has. In it, too, are to be found sulphuric acid, which is an oxide of sulphur; phosphoric acid, which is an oxide of phosphorus; and its leading solid constituent, urea, is the representative of bodies which arise when processes of oxidation have been going on.

2d. The expired and transpired matters present similar burned compounds. At the head of these products stand carbonic acid gas, which is an oxide of carbon, and water, which, as we have already said, is an oxide of hydrogen. We here omit any consideration of the nature or constitution of the fæcal matter, because much of it has never been properly in the interior of the system, though it has passed through the intestine.

The general result at which we arrive is, then, that the food consists of combustible matter, and that the substances dismissed from the economy are oxidized bodies. A burning must, therefore, have been going on, and this could only have been accomplished by the air introduced by breathing acting upon the substance of the body itself and its contents, and, to repair the waste which must have ensued, a due weight of food has been required. Since this, in its turn, as a part of the living mechanism, is destined to undergo the like destructive action, we may present the entire series of facts under consideration correctly by regarding them as arising remotely from the action of the air upon the food.

Combustion occurs in the body.

With this statement before us, we next inquire what ensues when substances appropriate for food are exposed in artificial experiments at a certain temperature to the action of atmospheric air.

A piece of flesh, or even of any vegetable body, consisting of carbon, hydrogen, oxygen, and nitrogen, submitted to those conditions, undergoes combustion. Its carbon, by uniting with oxygen, produces carbonic acid, its hydrogen for the most part water, but a residue thereof, combining with the nitrogen, may give rise to the production of ammonia. If there be any sulphur and phosphorus present, they also burn, and salts of sulphuric and phosphoric acids are the result.

Results of artificial combustion the same as that in the body.

Such is what occurs outside of the body in a common case of artificial combustion where atmospheric air has access. The constituents of which the food is composed thus satisfy their chemical affinities, and the com-

pounds we have mentioned arise. Now it is a fact of the utmost significance that the compounds thus originating from the direct artificial burning of matters proper for food are the very same that are dismissed from the animal system in which food has been submitted to the air introduced by respiration. They are such substances as carbonic acid, water, ammonia, sulphates and phosphates.

It may impress these truths more deeply upon us to learn that the facts at which we have thus arrived may also be recognized in the changes of destruction presented by the vegetable kingdom. The leaves of trees, after they have fallen in autumn, quickly decay, and even the heart-wood itself has a limit beyond which it does not last. Sooner or later every part of a plant is destroyed by the atmospheric air. Such limits of duration in animal structures are short. A very brief time, perhaps only a few hours, is all that is wanted for putrefaction to set in, and the entire mass, undergoing dissolution, is lost in the surrounding air.

This final disappearance of all organized structures is brought about by the action of that energetic element, oxygen. If by any contrivance its influence is prevented and its presence avoided, these changes do not take place. Putrefaction and decay are slow combustions, true burnings taking time. There equally arise from the fallen leaf and from the decaying body carbonic acid, water, and ammonia, the self-same substances dismissed from the economy during the continuance of life.

Processes of combustion and processes of decay are therefore both due to the action of atmospheric oxygen on the changing substance. They differ chiefly from one another in the relative rapidity with which they are accomplished.

Production of animal heat.

The facts thus set forth warrant the following statements. The matters which a man receives as food are combustible bodies; those dismissed from his system have been burned. To that, as to any other such burning, oxygen gas is absolutely requisite. There is, therefore, a plain conclusion before us, which, in its far-reaching consequences, covers the whole science of physiology, and betrays to us the function which every animal discharges, viz., that oxidation is incessantly going on in the interior of the system through the agency of atmospheric air introduced by the process of breathing.

An animal, in this point of view, is an oxidizing machine, into the interior of which atmospheric air is constantly introduced. The active constituent, oxygen, satisfies its chemical affinities at the expense of those parts of the system which are wasting away. And as the act of breathing, that is, the introduction of this gas, takes place day and night, waking and sleeping, so too must the production of burned bodies; a part escaping by the lungs, a part by the skin, a part in the urine. To compensate the loss which ensues, nearly 1000 pounds weight of combustible

matter must be used in the course of a year, and, for reasons to be examined in detail presently, three quarters of a ton of water. But this is a very different conclusion to the notion of the ancient physicians, that an animal during its life is exempt from participating in external changes, and is an enduring monument of the power possessed by the VITAL FORCE of resisting all physical influences.

But carbon by uniting with oxygen can not turn into carbonic acid, nor can hydrogen turn into water, nor nitrogen into ammonia, without heat being produced. The very meaning we attach to the term indicates that every process of burning is attended with the liberation of heat.

In domestic economy, we protect ourselves from the cold weather of winter, or attain any high temperature we want by the oxidation of some of the forms of carbon, such as wood or coal, in fire-places or stoves. We know that for the production of a given quantity of heat a given weight of combustible matter and of air is required, and that by employing various mechanical contrivances for increasing the draught we can accelerate the burning.

Moreover, if in our laboratories we require the very highest temperature that can be artificially obtained, we resort to the burning of hydrogen. There are instruments, such as the compound blow-pipe, constructed on this principle. In the flame which arises in this combustion the most refractory substances melt or are deflagrated.

Production of heat in putrefaction and decay.

But it may be said that though when a substance is rapidly oxidizing it must be evolving heat, there is perhaps a slower kind of combination, in which the particles unite without any disturbance of temperature. What proof could be offered, for example, that a mouldering leaf is disengaging heat?

In answer to this it is not necessary to bring forward refined or direct experiments. Every leaf when it moulders is literally burning away. The extrication of warmth begins even when it is ready to fall. What does the farmer expect in making his hay, if he puts the grass up in too moist a state, or in too large a mass? The temperature does not stop at the stage of bituminous fermentation, but the stack most probably takes fire. Of course what is going on in the whole mass is going on in each separate leaf, undistinguishable, it is true, in the latter case, because the heat of a single decaying leaf, taken alone, may be carried off by the cold surrounding air, or by the contact of good conducting bodies, and so be lost to examination.

From agricultural operations we may also learn that what holds good for vegetable bodies is true for animal substances. Heaps of manure or of offal of any kind, if due access of air be given, exhibit the extrication of carbonic acid, steam, and ammonia, and the temperature promptly rises. The gardener avails himself of this fact. He uses the heat, as it is slowly

set free by the putrefaction of manure in his forcing frames, to bring forth plants in the early spring. There is no kind of decay, or putrefaction, or oxidation of organic matters, however slow it may be, that is not marked by the production of warmth.

Man, in a state of health, maintains a nearly uniform temperature. Neglecting slight variations, to be hereafter critically examined, it is 98 degrees. For the most part, it is immaterial in what climate of the earth he may reside, whether in the cold polar regions or the hot tropic; he is so constituted that, either through the provisions of his own organization, or by resorting to the adventitious aid of clothing, or to special articles of food, he can maintain himself at about the same degree; and as all this heat arises from interstitial oxidation continually taking place, it is obvious that within certain limits he has control over it. Thus, in the winter he sometimes resorts to violent muscular action in order to increase the rapidity of respiration and the destruction of muscular tissue; for the greater the quantity of air introduced in a given period of time, the higher the temperature rises, just as when we close the door of a stove, or place a blower on an anthracite fire, an increased draught is occasioned and the quantity of heat is increased. To breathe with rapidity and depth is certain to raise the temperature.

Heat of man: its cause.

On the contrary, in summer, when the heat is oppressive, we instinctively abstain from muscular exertion, tranquil and slow respiration goes on, and the temperature is kept down. Again, there are means of occasioning an increased liberation of heat by changing the nature of the food and using highly combustible material, such as the various kinds of alcoholic preparations. The chemical constitution of alcohol is such that in the act of burning carbonic acid and water are produced with the liberation of so much heat that chemists find it one of the most suitable means of attaining a high temperature. On taking preparations of this substance, such as distilled liquors or wines, the first effect is the production of a genial warmth all over the body, intoxication eventually coming on as a secondary result.

These remarks are not limited in their application to our own species, the whole animal world furnishes us with commentaries on their truth. Man maintaining a temperature, as has been said, of about 98 degrees, other animals are at other degrees, some being cold-blooded and some hot. The particular point they reach depends, as direct observation shows, on the quantity of oxygen they consume, or, in other words, on their respiration. Birds, whose breathing mechanism is by far the most elaborate and extensively developed, have by far the highest temperature. The snake or the tortoise, whose rate of respiration is very slow, and which consume but little oxygen, have a correspondingly low degree of heat.

And in those creatures which at one period of the year are in full activity, but at another lie dormant or hibernate, as they begin to respire more slowly their temperature begins to decline, and when they have sunk into their winter's sleep their breathing is scarcely perceptible, and their warmth scarcely above that of the surrounding air.

In what has been thus far said we have been considering those operations of the system which tend to the production of heat, and the maintenance of the whole mass of the body at a temperature above that of the surrounding air. But it is obvious that provision must be made to prevent any undue rise, so that between those causes of elevation and these of depression a due equilibrium may be maintained. If a very large quantity of combustible matter, under the form of food, and about an equal weight of oxygen, are necessary for obtaining a proper heat, we should also recollect that nearly three quarters of a ton of water are consumed each year. The duty which this water discharges we may next consider.

Causes of cooling of the body.

Uses of water.

That duty is twofold. 1st. The removal of solid material in a state of solution; and, 2d. The production of cold by evaporation. It is the cooling agency which is of most interest to us in our present inquiry, but a few remarks as regards the removal of solid matter may not here be misplaced.

1st. Water, then, exerts its solvent power for the removal of all those substances which, arising incessantly in the animal system, can not assume either the vaporous or gaseous state. In this condition are the different saline bodies, such as the sulphates which are coming from the destruction of the muscular tissues, as voluntary and involuntary motions are performed; or the phosphates which are produced by the destruction of cerebral and nervous matter. In the same condition stand nearly all the nitrogenized results of the destruction of the soft parts, and which are to a great extent to be removed as urea. Water dissolving with more or less facility these various bodies permits their escape from the system by the secreting action of the kidneys, which, straining or filtering them from the blood, dismiss them to the bladder, from which they are periodically removed.

Its solvent power.

The skin is no inefficient auxiliary to the kidneys in effecting this removal of water charged with soluble matters. All over its surface are scattered in profusion the ducts of the perspiratory glands, which consist of a convoluted tubing abundantly supplied with blood-vessels. The final mode of action of these glands depends on extraneous circumstances. Most commonly the fluid is carried away under the form of a vapor or insensible perspiration, but when the secretion goes on more rapidly, or the dew-point of the surrounding air is high, it then accumulates as drops of sweat. The amount of water thus removed, even by insensible perspira-

tion, is greater than might be supposed, yet it corresponds with the extent of the provision. The length of the water-secreting tubing in the skin of a man is about twenty-eight miles.

Thus by the action of the kidneys and the skin large quantities of water are dismissed, either under the liquid or vaporous form. A third organ is concerned in this important duty. It is the lungs. These, however, are limited in their operation to its exhalation as vapor or steam. That water abundantly escapes from them is plainly shown when the days are cold, the moisture as it comes from the respiratory passages condensing into a visible cloud when it encounters the air. It is estimated that the loss of water by the skin and lungs conjointly is about 18 grains in a minute, of which 11 pass off from the skin and 7 from the lungs. Making due allowance for the variable action of the skin as dependent on the dew-point and other such causes, we can scarcely set down the entire quantity at less than 1000 pounds a year. In the same period the quantity of water lost as urine may be taken at 900 pounds. It may perhaps be remarked, that here we are assuming a loss of 1900 pounds, when the quantity of water annually taken is only 1500 pounds. But it is to be recollected that not only does water form a very prominent constituent of the solid food, whether vegetable or animal, but also that much arises from the oxidation of hydrogen in the interior of the system.

Cooling influence of water.

2d. Water also exerts a cooling influence, arising from its evaporation from the surface of the skin and the cells of the lungs. The difference between water in the state of an invisible vapor and in the liquid condition consists in this, that the vapor contains 1114 degrees of heat which the liquid does not. When, therefore, it evaporates from a surface of any kind, as from the skin, it obtains therefrom that large amount of latent heat, and so tends to cause the temperature to decline. Not that this is the only cooling agency at work. Radiation might also be mentioned; for, just as a warm inorganic body cools by the escape of radiant heat from it, so too does a living being.

Equilibrium of heat in man.

These considerations explain how an equilibrium of temperature is established. By the process of respiration there is a constant tendency to increase the heat; but by evaporation of water, radiation, and other cooling causes, there is a constant tendency to diminish it. A balance is struck between the two processes, and in man a temperature of 98 degrees is kept up.

This average temperature is, however, easily departed from. Through some trivial cause the cooling agencies may be interfered with, and then, the heating processes getting the superiority, a high temperature or fever comes on. Or the reverse may ensue. In Asiatic cholera, the constitution of the blood is so changed that its cells can no longer carry oxygen into the system, the heat-making processes are put a stop to, and,

the temperature declining, the body becomes of a marble coldness characteristic of that terrible disease.

The animal mechanism is thus the focus of intense chemical changes, and great quantities of material are required in very brief spaces of time for its support. We have seen what is the use of the combustible matter employed as food, what of the water, what of the air, how, these reacting on one another, a high but regulated temperature is kept up.

Necessity of repair in the system as it wastes.

Much of what has been thus far said has had reference only to the destruction of tissues. This waste of matter arises for a double reason, partly to give origin to the heat which animals require, and partly as a consequence of intellectual activity and muscular motion; for no movement can be made without a destruction of muscular fibre, and all mental and nervous actions imply the waste of a certain quantity of vesicular substance. For this reason, after an animal has undergone violent muscular exercise, the quantity of urea and sulphuric acid in the urine is increased, this being the channel through which those results of the destruction of muscular fibre are removed; or, after severe mental or intellectual duty, there is more phosphoric acid than usual in the urine, because of the greater oxidation of phosphorus which has taken place in the brain.

But of course this destruction of tissue must be compensated by a repair if a normal condition and health are preserved. The action of the air is not directly upon the food, for intermediately and temporarily the food is converted into the living mechanism. The dead material is awakened into life, and for a time, though only for a time, becomes a portion of the living and feeling mass.

The functions and actions we have been considering imply the provision of many complicated mechanisms. There must be means for effecting the introduction of the air; these, in man, depend on calling into operation its pressure. A system of tubes is necessary for its distribution to the points at which it is required, and in like manner a system is required for carrying away the wasted products of decay. The new material which is destined to replace the parts which are thus disappearing, and to keep the economy in repair, must be submitted to such processes of mechanical and chemical preparation that it may be dissolved in the blood, and carried wherever it is wanted. It must therefore be cut and crushed by teeth driven by powerful muscles, dissolved by acid and alkaline juices in digestive cavities set apart for that purpose. From these it must be taken by arrangements which can absorb it and carry it into the torrent of the circulation. Physical means must be resorted to, not only for the impulsion of these newly-absorbed nutritive juices, but likewise to drive the blood in its

Various mechanisms wanted for removal of waste and for repair.

proper career of circulation. It is needless here to dwell on the manner in which the most refined principles of hydraulics are brought into play, or to speak of the manner in which forces of compression and elasticity are introduced; how that there are valves which open only in one way to let the current pass, or how some of these, as in the like human contrivances, are tied down in their action by cords. Moreover, since it is required that the animal shall go in search of its food, muscles of locomotion, which act upon purely mechanical principles on the bony skeleton, must be resorted to, and so the animal structure becomes a most elaborate and complicated machine.

Physical aspect of man.

In this regard the human body may be spoken of as a mere instrument or engine, which acts in accordance with the principles of mechanical and chemical philosophy, the bones being levers, the blood-vessels hydraulic tubes, the soft parts generally the seats of oxidation. But if we limit our view to such a description, it presents to us man in a most incomplete and unworthy aspect. There animates this machine a self-conscious and immortal principle—the soul.

The soul: its nature and responsibilities.

Though in the most enlarged acceptation it would fall under the province of physiology to treat of this immortal principle, and to consider its powers and responsibilities, these constitute a subject at once so boundless and so important, that the physiologist is constrained to surrender it to the psychologist and theologian, and the more so since the proper and profitable treatment of it becomes inseparably involved with things that lie outside of his domain.

Yet under these circumstances, considering the ever-increasing control which scientific truth exerts over the masses of men, considering too how much the welfare of the human family depends on the precision and soundness of its religious views, it is the duty of the physiologist, if for the reasons that have been specified he yields this great subject to others, to leave no ambiguity in the expression of the conclusion to which his own science brings him. Especially is it for him, whenever the opportunity offers, to assert and to uphold the doctrine of the oneness, the immortality, the accountability of the soul, and to enforce those paramount truths with whatever evidence the structure of the body can furnish.

For this reason, he can not recall but with regret the existing use of many terms, such as mind, intellect, vital principle, spirit, which, though they were at first doubtless employed as expressions of the functions or qualities of the soul, have in the course of time gathered other meanings and confused the popular ideas. They have brought about a condition of things in science not unlike that which prevailed in theology during the reign of polytheism. Constrained, perhaps, himself by the necessities of language to use such phraseology, it is for him at the outset to leave no doubt of the views he entertains, and, as far as he can, prevent such

expressions from frittering away the great truth that, as there is but one God in the universe, so there is but one spirit in man.

On one of these terms, the vital principle, I may make a few remarks, since, from being a mere expression of convenience, it has by degrees risen among physicians and physiologists to the rank of designating an existing agent, by some regarded as of the same kind as light, heat, electricity, or gravitation—nay, even superior to them, since it is its peculiar attribute to hold them all in check. Animated by this extraordinary power, organic substances are supposed to withstand every external influence, and to submit to physical agents only after this principle has left them. Such a preposterous doctrine will not bear the touch of exact science for a moment. It is only a relic of the old metaphysical system of philosophizing, which accepted a name in lieu of an explanation, which preferred the dogma of the horror of a vacuum to the more simple but material view of the pressure of the air. By the aid of this imaginary principle, complete physiological systems have been woven, in which every act and every condition of the animal economy is spontaneously explained, and nothing remains for solution. But by the student of nature, whose mind has been trained in positive science, the imposture is detected. He sees at a glance that this is not the style of the Great Artist. The problems of organization are not to be solved by empirical schemes; they require the patient application of all the aids that can be furnished by all other branches of human knowledge, and even then the solution comes tardily. Yet there is no cause for us to adopt those quick but visionary speculations, or to despair of giving the true explanation of all physiological facts. Since it is given us to know our own existence, and be conscious of our own individuality, we may rest assured that we have what is in reality a far less wonderful power, the capacity of comprehending all the conditions of our life. God has framed our understanding to grasp all these things. For my own part, I have no sympathy with those who say of this or that physiological problem, it is above our reason. My faith in the power of the intellect of man is profound. Far from supposing that there are many things in the structure and functions of the body which we can never comprehend, I believe there is nothing in it that we shall not at last explain. Then, and not till then, will man be a perfect monument of the wisdom and power of his Maker, a created being knowing his own existence, and capable of explaining it. In the application of exact science to physiology, I look for the rise of that great and noble practice of medicine which, in a future age, will rival in precision the mechanical engineering of my times. In it, too, are my hopes of the final extinction of empiricism. Even now this method is attended with results which must commend it to every thoughtful mind, since it is connecting

The vital principle.

Importance of physical science in physiology.

itself with those great truths which concern the human family most closely, and is bringing into the region of physical demonstration the existence and immortality of the soul of man, and furnishing conspicuous illustrations of the attributes of God.

CHAPTER II.

OF FOOD.

The natural Subdivisions of Physiology.—Of Food: its Sources and Classification—its Value not altogether dependent on its Composition.—Of Milk: its Composition, and Use of its Water, Casein, Sugar, Butter, and Salts.—Variations in the Composition of Milk.—Of Bread.—Of mixed Diets.—Of the embryonic Food of Birds.—Nutrition of carnivorous and herbivorous Animals.—Food formed by Plants and destroyed by Animals.—Uses of mixed Food and Cooking.—Absolute Amount of Food.

Subdivisions of physiology.

PHYSIOLOGY possesses a very great advantage over many other sciences in offering its leading problems and doctrines in a certain well-marked order or sequence, a connected whole, with only here and there points of digression, but those points often of very striking interest. Thus pursuing the train of reflections entered on in the preceding chapter, we should have to consider the nature of the food, the manner of its preparation by the process of digestion, the mechanism by which it is taken up from the cavities in which it has been so prepared, and that by which it is distributed to every part. We should have to show the way in which it becomes incorporated as a portion of the living mass, its duration in that condition, and the manner of its decay. We should have to show by what physical means and through what mechanism the air is introduced to effect the destruction of the dying parts, and how, as the consequence of this, a fixed temperature is maintained. The causes which lead to variations of this temperature, and the manner in which the wasted products are removed by the skin, the lungs, the kidneys, might next obtain our attention. The complicated machinery necessary to accomplish all these purposes requires to be made to act in unison in all its different parts, a condition which introduces to us the nervous system. A consideration of the structure and gradual development of this system leads to the structure of the various organs of sense, and to the operations of the intellectual principle itself. Thus in succession we should have to treat of digestion, absorption, circulation, respiration, secretion, nutrition, and innervation, and to close the whole with the consideration of reproduction. This is the order which I propose to follow, and shall devote this chapter to the nature and qualities of the food.

Sources of food for animals and plants.

The supply of food to animals requires a more complicated provision than it does to plants, in which the elaborating organs, the leaves, presenting themselves superficially, are always in contact with the air, from which much of their nutrition is derived. And as one portion after another becomes exhausted, it is renewed by simple mechanical agencies, such as the trembling of the leaf, the warmth of the sun, or the winds.

Food, therefore, comes spontaneously to plants, which need no powers of locomotion. And though, as we shall hereafter find, muscular movement requires as its essential condition the waste of tissue, it is not necessary for their nutrition that plants should destroy organized substance. But an animal must seek its food, and for this purpose is endowed with locomotion, involving the destruction of tissue. In a chemical point of view, plants are organizing, and animals destroying machines. Nor is this general assertion controverted by the apparent exceptions which are here and there presented, as, for example, that the herbivora can form sugar and fat from food in which those substances did not pre-exist, and the salts of the biliary acids, which are never found in plants.

To obtain for animals the necessary supply of nutriment, the resources of nature are displayed in the most wonderful contrivances. According as their modes of life may be, one takes its food with its teeth, another with its lips, another with its fore member, another winds around it its whole body. The geometrical spider weaves a net, and lies in wait for his prey; the ant lion digs a pit in the sand. Some rely upon labor, some upon force, some upon fraud. Man depends upon all.

Classification of food into histogenetic and calorifacient.

Viewed as regards its physiological distinction, the food is generally considered as of two kinds: Histogenetic or tissue-making, and Calorifacient or heat-making. Histogenetic food furnishes the chemical substances—carbon, hydrogen, oxygen, nitrogen, sulphur, chlorine, phosphorus, iron, potash, soda, lime, &c. Calorifacient food furnishes carbon and hydrogen mainly. In consequence of this chemical constitution, tissue-making food is sometimes called nitrogenized, and heat-making non-nitrogenized food. The former is also sometimes designated nutritive, and the latter respiratory.

It is, however, to be distinctly understood that these divisions are only adopted for the sake of convenience, and that they have no natural foundation. Thus it will be found, when we examine the functions which the fats discharge, that though they are non-nitrogenized bodies, and are, therefore, considered as belonging to the class of respiratory food, there is every reason to believe that they are essentially necessary to tissue development, and that the metamorphoses of nitrogenized bodies can only go on in their presence. They are, therefore, as truly essential to nutrition as are the latter substances.

So, too, as respects the albumenoid bodies, of which it would be incorrect to speak as though they were limited to nutrition. In their decay or descending metamorphosis in the organism, they give rise to the evolution of heat, and are at last dismissed under the aspect of products of oxidation. They are, therefore, as far as this goes, as much respiratory food as are the fats themselves.

Other classifications of food. Perhaps the most convenient subdivision of food articles is presented in the four following groups:

1st. Carbohydrates, or compounds in which carbon is united with hydrogen and oxygen, their proportion being that for forming water. Starch, sugar, gum, cellulose, are examples.

2d. Hydrocarbons. Compounds containing unoxidized hydrogen. The oils, fats, and alcohol, are examples.

3d. Albumenoid bodies. These contain nitrogen. Albumen, fibrin, casein, are examples.

4th. Salts. Any classification of food articles which does not contain this group is imperfect; for salts are not only absolutely essential to organic processes, but also to the construction of many tissues. As an example of the former case, the chloride of sodium may be mentioned; and of the latter, the phosphate of lime.

Value of food does not depend wholly on its composition. It has been supposed that the tissue-making power of any kind of food depends on the quantity of nitrogen it contains, and that its value may therefore be determined by chemical analysis. Upon this principle tables have been constructed, showing the agricultural worth of different articles of forage for domestic animals. But, as will be found hereafter, when we consider the physiological effect of the allotropism of bodies, these tables are not of the use supposed. Without entering into details at present, the case of gelatin may be taken as an example; this, though a substance abounding in nitrogen, possesses no tissue-making value, but in reality belongs to the calorifacient class, and therefore its administration in the sick-room, under the various well-known forms of jellies, soups, etc., is altogether deceptive as regards any nutritive power, since it undergoes speedy oxidation in the system, and the products of its change escape by the kidneys and the lungs. The value of food is not only dependent on the occurrence of certain chemical elements; they must also be present in certain allotropic states.

The same remark applies to the tables which have been constructed, showing the amount of caloric furnished by different varieties of heat-making food. The quantity of heat set free during the combustion of a substance depends not only on the nature of the elements composing it, but also on the particular states in which they occur. Combustibles may have the same chemical composition, but very different heating power.

Food which is typically perfect, is presented by nature to the young of various animals. In milk, or in the egg, we should expect to find whatever is necessary for the growth of the tissues, and for the performance of the functions. An examination of milk will therefore illustrate the essential characters of the different elements of food.

Milk as an article of food: its composition.

Composition of Milk.

Water	873.
Casein	48.
Sugar of milk	44.
Butter	30.
Phosphate of lime	2.30
Other salts	2.70
	1000.00

In this we notice, first, the large proportion of water present, almost nine tenths of the whole amount. The double duty of this water has already been mentioned, to remove from the system effete substances which are not of a vaporous or gaseous form, and which can not escape through the lungs, and to regulate the temperature by evaporation. We might have added to these that it imparts a due fluidity to the blood. These are conditions as necessary to the infant as to the adult, and it should be remembered that two thirds of the weight of the body are water.

The water of milk.

Next follows the nitrogenized principle casein, which is closely related in composition to muscular flesh. It is the tissue-making, histogenetic, or nutritive element of the milk, and has been elaborated from the albumenoid substances of the mother's system. It is to be converted into the muscular, gelatinous, and other soft tissues of the infant.

The casein of milk.

Casein is one of a group designated as the neutral nitrogenized bodies, of which some of the more prominent are albumen, fibrin, and globulin. From an opinion that these all contain the same organic radical, they are often termed the protein bodies. They appear to exist in two different physical conditions, soluble and insoluble in water; they all contain sulphur, and exhibit a proneness to pass into the putrefactive fermentation. As this takes place when they have reached a certain stage of decay, they act upon other bodies as ferments. Their constitution is represented in common by the formula

Nature of protein bodies.

$$C_{48}\,H_{36}\,O_{14}\,N_6.$$

Of the whole group, albumen may be taken as the type and most important member. Indeed, as will be found hereafter, in the process of digestion the others are invariably converted into it. The white of the egg and the serum of the blood are usually referred to as examples of albumen, though they differ in several particulars from one

Albumen.

another. Albumen forms basic, neutral, and acid compounds. It is a basic albuminate of soda which is found in the egg and in serum of blood. In certain diseased conditions the blood contains the neutral albuminate.

Casein.

Casein presents nearly the same constitution as albumen, but differs from it in its physical properties; for, while a solution of albumen is coagulable by heat, one of casein is not, but lactic and acetic acids coagulate it, though they have no such effect on albumen. While, so far as their protein nucleus is concerned, the two substances agree in composition, they differ in this respect, that casein appears to contain a less proportion of sulphur, and no phosphorus. It is interesting to remark that, during incubation, casein arises from albumen in the eggs of birds.

Fibrin.

Closely allied to albumen and casein, and having the same protein nucleus, is fibrin, which likewise exists in two states, soluble and insoluble. Its solidification or coagulation can be produced by the action of sulphuric ether, which does not affect albumen. Moreover, in the coagulated state fibrin decomposes the deutoxide of hydrogen, but albumen does not. The most important difference between them is, that in the act of coagulation albumen shows no disposition to assume a definite structure, but fibrin does—fibrillating, as it is termed. The analogy of constitution and closeness of relation of the two substances is demonstrated by the fact that by nitrate of potash coagulated fibrin may be changed into albumen, and the same conversion is accomplished in the stomach by the digestive juices.

It is generally supposed, however, that fibrin contains a larger proportion of oxygen than albumen, a conclusion which seems to be confirmed by physiological considerations respecting its origin. For this reason, Mulder describes it as a higher oxide of his hypothetical protein. It always is associated with fat, or, perhaps more correctly, with soaps of ammonia and lime.

Fibrin is found in the chyle, lymph, and blood. In the latter fluid its quantity varies in different parts of the circulation. The blood of the portal vein yields it in smaller proportion than that of the jugular. It is also affected very much by diet: thus Lehmann found that under an animal diet there was much more fibrin in his blood than under a vegetable one, a result which has been confirmed by experiments on dogs. It has also been observed that its quantity is increased during starvation. But the blood of herbivorous animals contains more than that of carnivorous ones, and that of birds contains the most of all.

These remarks on the composition and physical properties of casein, albumen, and fibrin, have been introduced for the purpose of illustrating the facility with which these bodies are mutually convertible, and more

particularly for showing that there is nothing whatever mysterious in the casein or curd of milk arising from the albuminous serum of the mother's blood, and being transmuted into the fibrin structure of the muscular tissues of the infant.

Returning now to our examination of the composition of milk, as set forth in the preceding table, we find that two respiratory elements are next upon the list: 1st. Sugar of milk, which is to be converted into lactic acid, partly by the agency of the saliva, and chiefly in intestinal digestion; 2d. Butter, which is the oleaginous or fatty portion, and of which a part is to be deposited in the adipose tissues for a time of need, and a part, along with the lactic acid and excess of sugar, is to be burned at once for the production of heat.

The sugar and butter of milk.

The inorganic body, phosphate of lime, is necessary for the earthy portion of the skeleton, and probably the reason of the introduction of casein, to the exclusion of other protein compounds, depends on the power it possesses of holding phosphate of lime in solution, not less than 6 per cent. of its weight of this earthy body being often obtainable from it. Among the other salts of the milk, chloride of sodium may be pointed out as of special importance. It undergoes decomposition in the system of the infant, its hydrochloric acid giving acidity to the gastric juice, its soda entering into the composition of the bile and various salivary secretions. It also imparts solubility to albumen, and, in some degree, regulates the facility with which that substance coagulates. It impedes the coagulation of fibrin.

The salts of milk, particularly bone-earth, and chloride of sodium.

Milk is not a chemical compound, but a variable mixture of different ingredients, which, under proper circumstances, may be separated. When the fluid is allowed to rest for some hours at the ordinary temperature, the fat-globules rise to the surface as cream, which, submitted to a strong agitation with air in the process of churning, forms butter.

Making of butter.

The casein of milk can be readily coagulated by rennet (which is the mucous membrane of the stomach of the calf) at a temperature of 120°. If parted from the residual whey, mixed with a little salt and yellow coloring matter, and subjected to the action of a suitable press, it is formed into cheese. No better examples of the tissue-making and heat-making elements of food can be offered than cheese and butter respectively.

Making of cheese.

When milk is exposed to the air, its sugar, under the influence of the casein or curd, gradually disappears, turning into lactic acid, and the milk becomes sour. The composition of sugar and lactic acid is such, that we might, without much error, say that an atom of sugar symmetrically bisected will yield two atoms of lactic acid. This effect is produced by the casein commencing to pass into a state of de-

Lactic acid in sour milk.

cay under the influence of the atmospheric air. It is likewise produced during digestion by the saliva, and also by the pancreatic juice. The turning sour of milk on the stomach is due to the transmutation of its sugar into lactic acid.

Physiological uses of milk.

An infant finds in its mother's milk whatever it wants for the growth of its own body. In its system the curd resumes the form of albumen, or passes into the condition of fibrin or sÿntonin, and in this manner its muscular and gelatinous tissues are made. The butter is deposited in the adipose cells, or burned at once for the production of animal heat, a part of it, however, being incidentally consumed, as will be hereafter explained, in the fabrication of fibrin and for other histogenetic purposes. The phosphate of lime is carried to the osseous system, now in a state of rapid increase, and bone is formed from it.

Various kinds of milk for different animals.

But though milk is so well adapted to the wants of infantile life, it is unsuited to the adult. Its nitrogenized principle, casein, though in sufficient quantity for the repair of muscular waste and development at the former period, is inadequate to these purposes at the latter, when destruction, arising from the incessant activity of the muscular system, is so greatly increased. It is interesting to remark how the composition of milk is modified when there is a necessity to meet these indications, its nitrogenized principle being increased in the case of animals such as the cow and horse, the young of which commence locomotion almost at birth, or at a far earlier period than the human infant. This excess of casein is necessary for the repair of the resulting waste.

The Constitution of Milk.

Source.	Casein.	Sugar.	Butter.
Goat's milk..........	80	40	40
Cow's milk	63	28	40
Human milk	32	36	29

This table presents an explanation of the unsuitableness which is sometimes remarked in the milk of the cow when used for the nourishment of children. Milk which is adapted to the wants of the calf is not adapted to the functional wants of the child. Experience has taught the nurse that these difficulties may in part be removed by diluting it with water and sweetening it with sugar, the effect of this being to reduce the percentage of the nitrogenized element, the casein, and to increase that of the respiratory, and so approximate the composition more closely to that of human milk.

Moreover, milk is not suitable as the sole nourishment of adult life, since it does not contain in sufficient quantity those phosphorized compounds which are necessary for the repair of the waste of the cerebral and nervous tissues, which at this period are much more active than in infancy.

Variations in the composition of milk from its normal standard are observed to depend upon age and bodily health. Young females, from fifteen to twenty, yield a milk more rich in solids than that which is given at thirty-five or forty. Gestation at a late period increases the solid portions. The following table of Vernois and Becquerel illustrates the influence of disease:

Influence of age and health on the composition of milk.

Influence of Disease on the Constitution of Milk.

	In Health.	Acute Disease.	Chronic Disease.
Water	889.08	884.91	885.50
Casein and extractive	39.24	50.40	37.06
Sugar	43.64	33.10	43.37
Butter	26.66	29.86	32.57
Salts	1.38	1.73	1.50
	1000.00	1000.00	1000.00

From this consideration of the nature and properties of the food of infancy, we may pass to the examination of that of the mature period.

Experience has shown that, of all articles of food, bread made from wheaten flour meets best the requirements of the adult life of man. It seems to contain all that is necessary for support. A very simple analysis will show how it presents both the respiratory and nutritive elements.

Of bread.

If such flour be made into a paste with water, and be gradually washed with a larger quantity, an elastic coherent mass is left, and the water assumes a milky turbidity. After a time it becomes clear, through the settling of a white precipitate, which is starch, the leading member of the respiratory group. The elastic substance is gluten, which is a true vegetable fibrin, mixed with another nitrogenized body, gliadine, which may be removed, along with a certain quantity of oil, by washing with ether and alcohol.

Examination of flour of wheat and of other grains.

Thus, simply by washing in water, flour may be separated into two physiological elements, respiratory and nutritive, the former being the starch, and the latter the gluten. The relative quantity of these substances differs in different samples of flour, and, other things being equal, the greater the amount of gluten the more valuable the sample, because the more nutritious. It is interesting to remark that the liquid from which the starch has settled, if brought to the boiling point, becomes turbid again, from the coagulation of the vegetable albumen it contains.

Other grains, treated in the same manner, yield similar results. The flour of barley and of the oat, when washed with water, do not, however, yield gluten, but a pure fibrin, with a separation of starch.

The fibrin occurring in these grains is replaced in other nutritious seeds, such as peas and beans, by legumin, which, like the casein of milk, does not coagulate by boiling, but merely forms tenacious skins as it is evaporated. These may be removed by skimming. This substance,

which presents many analogies to casein, is coagulable by acetic acid and alcohol, and, if mixed with sugar, turns curdy, and becomes sour from the presence of lactic acid. It differs from casein in not dissolving in concentrated acetic acid, and, when precipitated by an acid, being unacted on by carbonate of lime. It is, however, coagulated by rennet.

Thus, when we use bread made of any of the common varieties of flour, we find in it both kinds of food, the respiratory and nutritive—the former as starch, and the latter as fibrin.

Use of butter on bread.

But civilized man has greatly improved on the simple diet which Nature furnishes, and, without knowing the immediate or philosophical reason, has added articles which increase the respiratory element. The proverb says, "It is good to have bread, but it is better to have bread and butter." Let us examine why it is so.

Wheaten flour, in its relations to the animal system, is defective in one point—its respiratory element, the starch. Now the constitution of starch is, that in its dry state it contains much more than half its weight of water, none of its hydrogen being free, but all oxidized. It is, therefore, only by the use of very considerable quantities of bread that the necessary amount of respiratory food can be had for keeping up the temperature to the proper degree. But if butter be put upon the bread, the effect is different. In common with all oleaginous bodies, butter contains an excess of hydrogen, and therefore, under the same weight, possesses a very high heating power. The defect of the flour is thus compensated, and by the use of quite a moderate quantity a high temperature can be maintained.

It would be very interesting to examine in this way the physiological relations of the diets adopted by communities of men, and the great changes which, at quite a recent period, have taken place through the introduction of tea, coffee, and chocolate on an extensive scale among civilized nations. Before the discovery of the passage to the East by the Cape of Good Hope, and the establishment of direct commercial relations between Western Europe and China, the general diet of the agricultural classes consisted chiefly of the common products of the farm and substances readily obtained in domestic economy, such as bread, and cheese, and beer. In a theoretical point of view, we can scarcely conceive of a diet more conducive to the sustenance of the bodily frame. The constitution of wheat flour shows that it contains the elements necessary for life; and cheese, which may be regarded as the preserved curd of milk, is an excellent flesh-producing body, the casein of which it consists being readily convertible into muscle-fibrin. The common salt used in its preparation promotes the function of digestion, by furnishing hydrochloric acid and soda. In addition, there are also in the beer, an alcoholic and intoxicating liquid, all the advantages

Of mixed diets; as bread, cheese, and beer.

of a highly combustible body for the purposes of respiration. Whatever, therefore, is requisite for the well-being of the animal economy is present in abundance in such a diet.

From an examination of the diet-scales of the educational and invalid establishments of London, the prisons and the hospitals, Beneké obtains the result that the nitrogenized should be to the non-nitrogenized food in weight as one to five. From other data, Frerichs calculates that the diurnal consumption should be 2.17 oz. avoirdupois of nitrogenized, and 15.54 oz. avoirdupois of non-nitrogenized food, that is, about as one to seven. Whatever is taken more than this is superfluous.

Ratio of nitrogenized and non-nitrogenized food.

The peculiar advantages arising from the use of casein, which in a soluble form possesses the quality of dissolving large quantities of phosphate of lime, unquestionably determine its employment as a constituent of milk. But there are circumstances under which a necessity arises for the use of other nitrogenized compounds, such as albumen, in early nutrition; and then it is remarkable by what indirect methods the difficulty of its want of solvent power over that earthy body is compensated for. The fœtal period of the life of birds furnishes an example. In the egg there is, of course, whatever is wanted for the development of the young animal; for, merely by the process of incubation, or submitting the egg to a due temperature for a suitable length of time, with the access of atmospheric air, the young chicken forms, with all its parts complete—its bony, muscular, nervous systems, feathers, beak, claws. The phosphate of lime required for the skeleton is not present as such, but is formed as incubation goes on; for in the yolk there is free phosphorus, to which the air finds access through the pervious shell, and, effecting its oxidation, phosphoric acid is the result. This reacts on the carbonate of lime, of which the shell consists, decomposes it, and the phosphate of lime forms. For this reason we observe, as the incubation proceeds, that the shell becomes lighter and thinner. The albuminous fluid which constitutes the white of the egg has little power of holding bone-earth in solution; but by manufacturing the salt in this manner, as it is wanted, the development of the young bird goes on without difficulty. To insure the due supply of oxygen, an air-bubble is placed at the broad end of the egg, so that, should any transient circumstance interfere with the passage of air through the pores of the shell, there is a little reservoir of that material on which to rely.

Development of a bird from the egg: origin of its parts.

The mammalia find in milk all that they need in their infantile life for their nutritive purposes. In the same manner birds, in their fœtal life, have whatever they require in the egg. For the former, casein is the nutritive element; for the latter, albumen. In both cases a ready transmutation of that element into muscle-fibrin occurs.

At a maturer period of life, animals may be divided into two groups, carnivorous and herbivorous, or those which feed exclusively on flesh, and those which feed on vegetable substances. Between these may, perhaps, be introduced a minor group, partaking of the manner of life of both.

Nutrition of carnivorous animals.

The carnivorous animal finds in its prey all that is required for nutrition, and the discharge of its functions. Digestion under these circumstances is reduced to its simplest conditions, and is scarcely more than a process of solution. In the stomach the fibrin is brought into a soluble form; in the duodenum the fats are reduced to an emulsion. The digestive apparatus has but little complexity. The stomach may be regarded as a mere enlargement or pouch upon the alimentary canal, having, along with the intestine, the office of bringing the food into such a condition that it can be taken up by the veins and lacteals, and so pass into the circulation. The various constituents now revert into the same state in which they were before digestion began, the fibrin aiding in the repair of the wasted muscular tissues, and the fats being deposited in the adipose cells. The bones, feathers, and other such matters as have not been dissolved by digestion, are cast out.

In the production of heat and motion the carnivorous animal consumes itself, and, through the oxidation incessantly going on by means of the air introduced by respiration, carbonic acid, ammonia, water, sulphuric and phosphoric acids are constantly forming.

Nutrition of herbivorous animals.

On a superficial view it might be supposed that in the other group, the herbivorous, the case is quite different. These seem to spend all their lives in obtaining food. The ox or the horse, put out into the pastures, is all the day long cropping the grass. On a comparison of the quality and nature of the food which they take with the substances of which their bodies consist, there seems to be nothing in common. It was not, therefore, without reason that the earlier physiologists imputed to the digestive organs of this class the power of forming flesh and blood from vegetable matters. When, however, we come to a critical examination of the facts, we find that there is no essential difference between them and the carnivora.

When the expressed juice of vegetables is permitted to stand for a time, though it may have been clear at first, a turbidity sets in, and a flaky material is deposited. The substance thus possessing the power of spontaneous coagulation is identical in that property, and in composition, with animal fibrin. After its deposit, if the clear liquid be warmed to near the boiling point, it again becomes turbid, and a second nitrogenized substance subsides, which, from its quality of coagulating by rise of temperature and its analysis, is inferred to be identical with animal albumen. When this has been separated by filtration or otherwise, and the juice is

slowly evaporated, there come on its surface skins of a body having the same qualities as casein; so fibrin, albumen, and casein pre-exist in plants.

Fatty matters of every description may also be extracted from vegetable products. From leaves, seeds, bark, wood, etc., oleaginous bodies can be obtained by the action of sulphuric ether, which removes the fat, and leaves it on subsequent evaporation.

It being thus understood that the food of the graminivorous animals contains nitrogenized bodies and fats ready formed, we have clearer views of the function of digestion in those tribes. It is not necessary to impute to their digestive organs the power of creating flesh and fat from vegetable matter. The office of the animal is merely to collect. The two groups being compared together, the carnivorous animal receives under less compass the required amount of nutrition, and its digestive apparatus is more compact. But the graminivorous animal must all the day long collect large quantities of food, out of which it may extract the little nutrient matter they contain. The carcass of an animal, seized by a lion, is almost all digestible, but it would require a very large amount of herbage or of grain to be supplied to an ox to make up the same quantity of albumen or fat. Hence the necessary complexity and size of the digestive organs of the herbivorous group, and hence many of their habits of life.

Food formed by plants and destroyed by animals.

Moreover, we see that even in this apparently extreme case the animal system does not clearly exhibit any quality of exerting a formative action, nor of grouping atoms into a state of higher organization. It possesses no special power of making flesh. To the vegetable world we have to look as the great formative agent. In the organism of plants the various compounds wanted by animals are fabricated. Animals destroy those compounds, and in so doing maintain a high temperature, irrespective of atmospheric conditions, and give rise to the phenomena of motion and intellectuality.

Universal experience, as well as direct experiment, proves that in the case of man health can not be maintained on a uniform diet, however it may be with animals. A mixed food, which varies from time to time, seems to be essential; and there can not be a doubt that the changes which physicians have recognized in the nature of the predominating diseases, from century to century, are connected with changes which have taken place in the nature of the diet. The introduction of tea, coffee, the potatoe, and tobacco, must have made a marked impression in these respects.

Necessity of a mixed food for man, and use of cooking.

Undue excesses of albumen, oil, or starch, in the diet of an individual, produce a liability to arthritic, bilious, and rheumatic affections. An abstinence from fresh vegetables and fruits develops scorbutic, and a deficiency of oleaginous materials scrofu-

lous disease. It is evident that a control over these affections may be obtained, or even their cure, to a considerable extent, accomplished, by suitable changes in the nature of the food. This is strikingly seen in the improvement of the health of sailors during long voyages, since the introduction of vegetable preparations or acid juices. In 1726, Admiral Hosier sailed from England to the West Indies with seven ships of the line, and lost his whole crew twice by scurvy. The circumnavigation of the globe is now often accomplished without the loss of a single man.

I have already remarked the insufficiency of the tables setting forth the value of articles of food as dependent on their chemical constitution. Such tables are of little use, agriculturally, in the case of animals, and still less, physiologically, in the case of man. The art of cooking does not minister alone to the gratification of the palate, it lends a real assistance to the operation of digestion. New elements may not have been added, nor existing ones removed in submitting the food to the action of a high temperature, yet such a change is thereby impressed upon it that it becomes more capable of digestion, and more subservient to the wants of the economy.

The absolute quantity of food.

In determining the absolute quantities of nutrient substances required by the system, Lehmann observes that there are three magnitudes which we are especially called upon to consider: the first is, the quantity of food requisite to prevent the animal sinking from starvation; the second is, that which affords the right supply of nourishment for the perfect accomplishment of the functions; and the last is, that which indicates the amount of nutrient matter which may, under the most favorable circumstances, be subjected to metamorphosis in the blood. The method of finding the minimum of food necessary to support life by stopping all supplies without, and determining the quantities of matters which the organism uses by the excretion of urine, fæces, expired and transpired products, though it has yielded results of the utmost importance to science, is nevertheless not altogether reliable, for in such a state of inanition the system is brought into a morbid condition, or, at all events, is not acting in a normal way. Moreover, much depends on the activity with which the various functions are carried forward, a necessity for nourishment increasing with increase of external activity. And as to the amount of food demanded for the maintenance of the system at its standard, it must be borne in mind that of the four classes, the carbohydrates, the fats, the albuminous matters, and the salts, no one alone will answer the purpose, but all must be employed together, and this in variable proportion, according as the local, and therefore variable, wastes of the system may have been. These considerations indicate how complicated the problem we have in view really is.

From the experiments of Boussingault with reference to fat, and of Bidder and Schmidt with reference to the albuminates, and of Von Becker with reference to the carbohydrates, we learn that only definite quantities of these substances can be absorbed by the intestine in definite periods of time. This maximum limit is, however, far more than the necessities of the system require; hence in overfeeding, though much of the excess of food passes away with the excrement, a very large portion is, as it were, needlessly absorbed, and, undergoing metamorphosis in the blood, is removed by the kidneys. To this portion Lehmann applies the designation introduced by Schmidt, luxus consumption, or superfluous consumption. Of course, the simplest condition under which we can investigate the normal quantity of food required is that of an invariable weight, and the difficulties of the inquiry are increased when growth, corpulence, pregnancy, or other such states, are included.

Maximum limit of absorption of different elements of food.

Though we are very far from being able to offer a complete solution of the problem of the amount of food required, in its most general sense, yet, through the labors of many chemists, we have accumulated several facts which have a bearing on this question. Thus it is known that albuminous substances alone can not be absorbed in quantity enough to compensate for the loss of carbon by respiration. A duck, as is shown by Boussingault, expires in one hour 1.25 grammes of carbon, but can only absorb of carbon in albuminates 1.00 gramme. So, in like manner, fat alone is inadequate, for of this substance 0.84 gramme, containing about 0.70 gramme of carbon, can only be taken up in an hour, and this is not much more than half of what the respiratory operation demands. The carbohydrates, however, can be absorbed in sufficient proportion, and in this mixed manner are all the requirements satisfied. Boussingault makes the curious remark that, in the quantity of starch, 5.26 parts, and the quantity of sugar, 5.62 parts, which this bird can absorb in one hour, there are nearly the same quantities, 2.37, of carbon.

Among the special investigations which have been made to determine the amount of food used and the amount of educts from the system, should be mentioned that of Valentin upon himself. His weight was 117 lbs.; his diurnal consumption of food, 6.451 lbs.; solid excrement, .42 lb.; urine, 4.686 lbs.; and 2.751 lbs. perspiration. From the more recent and very exact experiments of Barral, it is inferred that of 100 grammes of carbon which have been absorbed into the organism, 91.59 escape as carbonic acid through the lungs and skin, 4.58 appear in the urine, and 3.83 are re-excreted and appear in the fæces. Upon similar principles, Lehmann computes, from the data furnished by Barral, that for every 100 parts of absorbed nitrogen, 49.6 parts are removed through the skin and lungs, 42.07 are found in

Amount of food, and amount of loss.

the urine, and 8.33 are re-excreted into the fæces. As a general result, it follows, from these experiments, that an adult man oxidizes, on an average, 289 grammes of carbon, and 18.6 grammes of hydrogen in twenty-four hours.

CHAPTER III.

OF DIGESTION.

TISSUE-MAKING OR HISTOGENETIC DIGESTION.

Nature of Digestion.—The Mouth, Teeth, Stomach.—The Salivary Glands.—Different Kinds of Saliva.—Properties of mixed Saliva: its Quantity, Composition, and Functions.—Relation of the Salivary Glands and Kidneys.—The digestive Tract.—The Stomach.—Gastric Juice.—Organs for its Preparation.—Manner of producing Chyme.—Influence of the Nerves.—Artificial Digestion.—Preparation and Properties of Pepsin.—Regional and functional Divisions of the Stomach in Animals and in Man.—Object of Stomach Digestion.—Peptones.—Use of Salt.—Digestibility of various Articles of Food.

Nature of digestion.

BEFORE the food can be absorbed and carried to all parts of the system it must be submitted to certain preparatory operations. Since it is either to be dissolved in the blood or transported as chyle through the lacteal vessels, it is absolutely necessary to bring it into a condition of solution in water, or at least into a state of minute suspension in that liquid. Received in masses of a certain size, it is first cut and crushed into smaller portions by the teeth, and then brought from an insoluble into a soluble or suspended state by the chemical action of the digestive juices.

Functions of the mouth.

In the mouth the food is submitted to a twofold preparation. It is divided by the mechanical action of the teeth, and also simultaneously mingled with liquids secreted from the salivary glands.

Instruments of comminution in various animals.

The animal series present us with numberless contrivances for accomplishing this comminution. The teeth, though of a bony nature, are not to be regarded as appertaining to the skeleton, but rather to the digestive mechanism. Their structure, number, and position differ very much in different tribes. In certain fishes the mouth is almost lined with them. In crabs they extend to the stomach, but in other cases they are restricted to the pharynx, or are wholly absent; this being the case, for instance, among the ant-eaters. Those insects whose food is of a fluid nature have no need of teeth; but those which use solid material are accommodated with suitable instruments of abrasion, such as borers, chisels, saws, nippers, the particular mechanism re-

sorted to being adapted to the nature of the food. It is to be understood that these mechanical terms are not mere metaphors, they indicate the actual nature of the apparatus. The object aimed at is to obtain the food in such small portions, and in such a bruised or pulpy condition, that digestion can be accomplished promptly. In man the number of temporary teeth is twenty, ten in each jaw. They are arranged in three classes—four incisors, two canines, and four molars for the upper and under jaw respectively. The permanent teeth, which are eventually substituted for these temporary ones, are thirty-two in number, classified for each jaw as four incisors, two canines, four bicuspids, and six molars. Their arrangement is exemplified in *Fig.* 1, representing the lower jaw, in which *i* is the middle and lateral incisor, *c* the canine, *b* the two bicuspids, and *m* the three molars.

The teeth.

Fig. 1.

The human lower jaw.

The movements of the teeth, aided by those of the tongue, accomplish a due abrasion of the food, and simultaneously incorporate it with the saliva. This is, therefore, a purely mechanical operation. It is analogous to the methods to which chemists resort in their laboratories when they prepare solid materials for exposure to reagents.

Mechanical nature of mastication.

The mingling of food with saliva, or insalivation, effects a double object. Coated over with a glairy juice, the bruised substance passes along the œsophageal tube into the stomach; but there are also certain chemical changes, which, commencing in the mouth, are of essential importance to the completion of digestion.

The stomach is an expansion of the alimentary canal between the œsophagus and duodenum, of a conical figure, the base of which is to the left. It communicates with the œsophagus by its cardiac orifice, and by its pyloric with the duodenum. It consists of three coats or tunics — the serous or peritoneal, which is exterior; the muscular, which is intermediate; and the mucous, which is interior. They are connected with each other by cellular tissue. The fibres of the muscular coat run in three different directions, constituting three layers; the superficial ones are longitudinal, radiating from the œsophagus over the surface of the organ; those of the middle layer are circular, or ring-like; they are well developed about the middle of the stomach, and by their contractions sometimes make it assume a divided appearance, as though composed of two compartments. Toward the pylorus they are also greatly re-enforced. The fibres of the third layer take, for the most part, an oblique direction. The interior or mucous coat is some-

Description of the human stomach.

times termed the villous, from its velvety appearance. Its color is very variable; it is folded into rugæ, which admit of variations in the distention of the stomach, without interference with the structure or functions of the membranes of which they are a part. The cardiac orifice is plicated, and the opening into the duodenum is through a circular fold with a central aperture—the pyloric valve, which being surrounded with a band of muscular fibres, acting as a sphincter, the passage from the stomach to the intestine may be entirely obstructed.

Fig. 2.

Section of the human stomach showing its mucous interior.

The stomach is seen in section *Fig.* 2, *a* being the œsophagus; *b*, the greater extremity; *c*, the smaller curvature; *d*, the great curvature; *e*, the pyloric or less end; *f*, *h*, the duodenum; *g*, place of entry of the ductus communis choledochus and pancreatic duct. The place of junction of the œsophagus is the cardiac region: the membrane is there plicated. The place of junction of the duodenum is the pyloric region.

Types of the stomach.

The typical form of the digestive apparatus is a sac with one aperture, which serves the double purpose of affording an entrance to nutritive material, and an outlet to undigested remains. In a higher condition it may be conceived of as a tube open at both ends, and having a sac-like swelling on its middle part. The portion of the tube anterior to the sac is the type of the œsophagus, its aperture answering to the mouth, the sac-like swelling being the type of the stomach, and the tube leading from it representing the intestinal canal. In the more elementary of such forms, vessels arise from the walls of the digestive cavity, and pass to all other parts of the system. These serve to convey the elaborated material. Certain appendages are soon to be discovered in connection with this simple digestive mechanism. They are for the preparation of salivary, gastric, pancreatic, or biliary juices. In size or development they vary with the habits of life of the animal, or with the nature of its food. Indeed, the same remark may be made as respects the entire digestive tract of the highest tribes. Thus, in the bat the length of the intestine is to that of the body as three to one, but in the sheep as twenty-eight to one. The ruminants generally have an intestinal tube of great length. In man and in monkeys the proportion is about five or six to one. Again, as regards construction, there are many

diversities, the number of digestive dilatations and their size corresponding in some measure to the nature of the food.

Different kinds of saliva.

Three pairs of glands, the parotid, submaxillary, and sublingual, secrete saliva. Of these organs the parotid is the largest; its secretion is delivered through the duct of Steno. The submaxillary duct is Wharton's, but the sublingual pours its fluid through many small apertures near the frenum linguæ. Besides these proper salivas, the lining membrane of the mouth yields a fluid, the buccal mucus.

The parotid saliva.

The parotid saliva is thin and watery, limpid and colorless, inodorous and tasteless. Secreted during fasting or under the use of stimulating food, it is denser. It contains so large a quantity of lime that, on exposure to the air, it becomes covered with an incrustation of the carbonate of that substance. It also contains sulphocyanide of potassium. Its organic ingredient, if not albuminate of soda, closely resembles that body.

From the chemical constitution of the saliva of the parotids, the physiological function of those glands, as aquiparous organs, is established. They yield a certain quantity of watery juice, which, by reason of its thinness or fluidity, is readily incorporated with the food by the teeth. Parotid saliva appears to have no power of transmuting starch into sugar.

The submaxillary saliva.

The submaxillary saliva is also colorless and limpid, tasteless and inodorous. It contains no morphological elements. It is lighter than the parotid, less alkaline, and contains less lime. For this reason, when exposed to the air, it does not become incrusted with carbonate of that earth. It contains sulphocyanide of potassium. It is so viscid and glutinous that it may be drawn into threads. From this physical property it probably facilitates deglutition by furnishing a kind of anti-friction coating.

The sublingual saliva.

The sublingual saliva is thin and watery, containing, like the parotid, but a small percentage of solid matter, and probably discharging a similar function.

The buccal mucus.

Besides the special salivary juices, the lining membrane of the mouth pours forth a liquid—the buccal mucus—a thick and tenacious substance, having many epithelial cells. It is alkaline in its reaction, does not coagulate on heating, its insoluble salts containing no carbonate of lime. It has been obtained for examination by tying the ducts of Steno and Wharton, keeping the nostrils open and the head inclined, so that, the animal being unable to swallow, the mucus flows out of the mouth.

The buccal mucus, if mixed with parotid saliva, does not appear to possess the power of turning starch into sugar, but, if mixed with the submaxillary secretion, it accomplishes that transmutation with facility.

The saliva, as obtained from the mouth, is therefore a mixture of the

secretions of the various salivary glands. It may be doubted whether the method of obtaining it sometimes recommended, by making pressure under the chin and tickling the fauces with a feather, yields it of normal constitution. It is described as an alkaline juice, of a bluish color or colorless, in consistency glairy, readily frothing, and therefore well adapted for entrapping atmospheric air. It contains, of solid matter, from 0.348 to 0.841 per cent. Its alkali appears, for the most part, to be combined with an organic substance, ptyaline, from which it may be separated by the weakest acids, such as carbonic. In the ash of saliva the alkali occurs chiefly as phosphate: this arises from rearrangement of the constituents during incineration. The saliva contains but a trace of alkaline sulphates, the chlorides of sodium and potassium preponderating over all the other mineral ingredients.

Properties of mixed salivas.

On standing, saliva separates into two layers: a transparent one, which is supernatant, and a grayish turbid one below, which consists of a deposit of particles of pavement epithelium and mucus corpuscles, derived from the lining membrane of the mouth and the salivary ducts. Its chemical reaction varies to some extent with the state of the system; thus, after long-continued fasting, from being alkaline, it may approach the neutral state. By some it is asserted that under these conditions it may even become acid. There is no proof that this is owing to the appearance of lactic acid: it may be due to butyric acid, or even the acid phosphate of soda. In morbid conditions this reaction is by no means infrequent: it has been commonly observed in intestinal inflammation, acute rheumatism, intermittent fever. Donné and Frerichs assert that acidity of the saliva depends on an irritation of the buccal mucous membrane.

The specific gravity of mixed saliva varies from 1.004 to 1.009. These variations depend on many different causes, there being a diminution after the taking of drink, and a greater increase after taking food, than even is observed in the fasting state. An animal diet especially increases it.

Under ordinary circumstances, the saliva is secreted to an amount of from 15 to 20 ounces daily. The exudation is more copious during mastication, speaking, reading, more being produced by the use of hard than soft food. Mental emotions exert a control over its flow, sometimes diminishing it, as in moments of anxiety, sometimes increasing it, as by the anticipation of food. After eating, the flow continues to a considerable extent; it is also provoked by the use of aromatics. On irritation of the interior of the stomach through a gastric fistula, the flow is simultaneous with that of the gastric juice.

Quantity of saliva.

The movements of the jaw and the pressure of the food give rise to variations in the quantity of saliva. It is perhaps for these reasons that the parotid gland on that side of the mouth which is most used in mastication secretes more than the other. Of the proportion of the different kinds of

saliva in the mixed secretion, nothing is known with certainty in the case of man, but it is said that in horses the parotids furnish two thirds, the submaxillaries one twentieth, and the sublinguals and mucous follicles the rest. The secretion of the saliva goes on during sleep.

To the active organic substance of the saliva the designation of ptyaline has been given. It is regarded as a ferment, possessing in several respects the properties of diastase, and hence has been called by Mialhe diastase salivaire. Ptyaline.

For the purpose of analysis, saliva should be obtained in a perfectly fresh state, a condition not easily fulfilled, for it decomposes or changes with rapidity.

During these changes, alkaline carbonates, for example, are formed in abundance, though they may have existed but to a small extent at first. We have already seen that in this way parotid saliva, exposed to the air, yields crystals of carbonate of lime. The following table is presented as offering an example of the average constitution of mixed saliva. Constitution of saliva.

Constitution of the Saliva (Frerichs).

Water	994.10
Epithelium and mucus	2.13
Fat	.07
Ptyaline and alcohol extract	1.41
Sulphocyanide of potassium	.10
Fixed salts	2.19
	1000.00

Of the fixed salts the chief are, the phosphates of soda, lime, and magnesia, and the chlorides of sodium and potassium. The sulphocyanide of potassium varies in amount considerably: it increases after meals, and especially after the use of condiments, salt, pepper, spices. Those articles which contain sulphur, as mustard, garlic, radishes, increase its amount in a very marked manner.

Not only does the saliva, as derived from the different glands, present differences of constitution; it likewise differs in various animals, and in the same animal according to its age. This is observed even in the case of man. The saliva of an infant at the breast possesses very little power of saccharizing starch, a transmutation which that of the adult accomplishes with energy. Modifications of saliva.

The action of this secretion appears to be limited to starch, and certain kinds of sugar, which first yield lactic and then butyric acid. It does not exert any influence in transforming albuminous matter.

The saliva discharges many functions. It is a necessary intermedium in the sense of taste, for substances to be sapid must be more or less soluble in this juice. If insoluble, they are tasteless. It also moistens the interior of the mouth, and prevents the sensation of Functions of saliva.

dryness. But its chief duty seems to be that of promoting the digestive operation; for, though the food remains in the mouth but a short time, the action of the saliva is prolonged after the masticated mass has been deposited in the stomach. Though the direct admixture of saliva with gastric juice injures the power of the latter, this effect does not ensue in the stomach, since they act for the most part separately. The action of the gastric juice is superficial, and two distinct operations are therefore conducted at the same moment, the surface of the food changing under the influence of the gastric juice, and the inner portion under that of the saliva. I believe that in this manner the salivary juice lends itself to stomach digestion, for it is well known that by its aid starch changes into grape sugar, and the transmutation does not stop at that point, but goes on to the production of lactic acid. An acid juice is essential to stomach digestion.

Action of the saliva is continued in the stomach.

After the administration of balls of starch to animals in which gastric fistulæ have been established, sugar may be detected in the stomach in the course of ten or fifteen minutes. It does not appear that there is any relation between the quantity of saliva incorporated by mastication and the quantity of starch in the food. Animals which swallow their food without mastication have either no parotids, or those organs exist in only a rudimentary state; commonly, however, their submaxillary glands are large. Under the most favorable circumstances, the digestion of starchy food is scarcely ever complete, a considerable portion being found in the excrement. The true function of the saliva has been well illustrated by inserting amylaceous food into the stomach of dogs with gastric fistulæ, after tying the salivary ducts, in which case no sugar can be detected.

Production of sugar from starch in the stomach by the saliva.

It has been suggested that the eventual arrest of the action of saliva on reaching the stomach may be due to the digestion of its ptyaline by the gastric juice. In artificial experiments, however, such a digestion or destruction can not be accomplished.

The double digestion, partly salivary and partly gastric, occurring in the stomach, is doubtless one of the causes of those differences which have been noticed between the natural action of that organ and the artificial imitations of it. The influence of the saliva, even under these, which may seem at first sight to be unfavorable circumstances, is far from being trivial, an effect which is well illustrated by the instantaneous manner in which a solution of starch in water, mixed with an equal quantity of saliva and agitated, is transmuted into a solution of sugar. In a few moments its viscidity is lost, it fails to give the blue reaction with iodine, becomes sweet to the taste, and readily answers to Trommer's test.

Besides the duties which have been mentioned, the saliva incidentally

accomplishes a secondary object by its power of retaining gases in its froth or foam. Atmospheric oxygen by this means is incorporated with the food during mastication, and is thus enabled to exert an important influence in promoting the action of the gastric juice. For to the inception of the change which that juice impresses on the food, oxygen is necessary. It is brought into the cavity of the stomach entangled or dissolved in the saliva.

Saliva carries air into the stomach.

It has just been mentioned that the action of saliva on starch is not restricted to the production of sugar, but that it may end in the formation of lactic acid. If, therefore, any thing intervenes to check the supply of hydrochloric acid, which usually gives acidity to the gastric juice, the system possesses within itself the means of compensating for the difficulty. In the interior of the digesting mass lactic acid is being set free. This acid, as has long been known, can replace hydrochloric acid in its physiological duty.

Lactic acid supplies deficiencies of hydrochloric.

Though so large a quantity of saliva as 20 ounces may be secreted in a day, this being about one half of the urinary discharge, it is to be remembered that the water is not lost to the system, as in the latter case. When the impure habit of profuse spitting is indulged in, it is interesting to remark the reflected effect which takes place in the reduced quantity of the urine, and an instinctive desire for water, a kind of perpetual thirst. It is probable that, under these disgusting circumstances, the percentage amount of saline substances in the saliva is increased, and that, so far as that class of bodies is concerned, the salivary glands act vicariously for the kidneys, and the mouth is thus partially converted into a urinary aqueduct.

Disgusting effect of profuse expectoration.

The relation between the salivary glands and the kidneys is very well shown after the administration of such substances as the iodide of potassium. If five grains of this salt be taken in pills, and the mouth be then thoroughly washed, in the course of a quarter of an hour the saliva will readily strike a blue tint when tested with nitric acid and starch, but the urine will not show that reaction until after a considerable interval, perhaps even an hour or more. It would therefore appear that such a salt must pass again and again through the salivary glands before it is finally disposed of by the kidneys, which offer the only outlet for its total removal.

Relation of the salivary glands and the kidneys.

Among the functions of the saliva we ought not to overlook the influence which its rapid secretion must exert on the state of tension of the blood-vessels, an influence which probably favors the absorption going on in the stomach and intestines.

Thus prepared by mastication and insalivation, the food descends into the stomach, passing along the pharynx, which dilates to receive it. The rima glottidis spontaneously closes, and additional security is given to the

respiratory passage by the valve-like shutting of the epiglottis. Through the œsophagus the morsel advances by the contraction of the muscular coat, with a wave-like or undulating motion onward. The food is now delivered at the cardiac orifice of the stomach, and, entering that organ, is submitted to the gastric juice, which is exuding from the mucous membrane.

Illustration of the digestive tract.

The digestive tract may be considered as presenting six prominent regions—the mouth, the pharynx, the œsophagus, the stomach, the small intestine, the large intestine. Their relative position and subdivisions are illustrated in Figure 3.—1, the tongue; 2, 2, the pharynx; 3, 3, the œsophagus; 4, the velum pendulum palati; 5, section of the larynx; 6, the palate; 7, the epiglottis; 8, the thyroid cartilage; 9, the medulla spinalis; 10, 10, bodies of vertebræ; 11, 12, spinous processes of ditto; 13, cardiac orifice of stomach; 14, splenic extremity; 15, pyloric extremity; 16, 16, greater curvature; 17, the less curvature; 18, pylorus; 19, superior transverse portion of duodenum; 20, middle or perpendicular portion; 21, inferior transverse portion; 22, gall-bladder; 23, cystic duct; 24, hepatic duct; 25, ductus communis choledochus; 26, its aperture in the duodenum; 27, duct of the pancreas, emptying into the duodenum near to the place of entry of the ductus communis choledochus; 28, commencement of jejunum; 29, 29, 29, jejunum; 30, 30, 30, ileum; 31, ileum opening into great intestine; 32, ileo-colic valve; 33, ileo-cœcal valve; 34, cœcum; 35, appendix vermiformis; 36, 36, the ascending colon; 37, transverse arch of colon; 38, descending colon; 39, sigmoid flexure; 40, rectum; 41, anus.

Fig. 3.

The human digestive tract.

From the interior or mucous coat of the stomach the gastric juice exudes. This fluid may be best obtained for examination by gastric fistulæ artificially established in animals. As respects the

aspect of the interior of the stomach, Dr. Beaumont, who had an opportunity of examining it in the case of Alexis St. Martin, describes it as of a light pink color, its velvety surface being coated over with mucus. On the introduction of food or any irritant, lucid points protrude from the mucous coat; these are the mouths of the follicles from which the juice exudes. When in activity, the temperature of the interior of the organ is about 100° Fahr.

Aspect of interior of stomach.

The gastric juice is a viscid fluid, with an acid reaction and faint odor. After filtration through paper it is clear and transparent, and possesses all its physiological qualities. The impurities thus separated from it are merely old undigested residues, on which, in no respect, its qualities depend. It does not become turbid at 212°, remains long undecomposed, and retains its digestive power even after it has become mouldy. It does not accumulate in the stomach while fasting, but requires a stimulus for its ejection, and even then is produced in a limited quantity only. It is secreted by the follicles of the mucous membrane of the stomach, which follicles may be described as cup-shaped cavities, about the two hundredth of an inch in diameter, from the bottom of which project two or more parallel tubes, the mouth of the cup opening into the stomach, and the tubes ending in a closed termination in the tissue beneath. Toward the pylorus the cups become deeper, so as to assume the form of a cylinder, and the projecting tubes are shorter. Between these follicles blood-vessels pass. They are ramifications from the cœliac axis, and discharge a double function. As the arterial branches invest the roots of the tubes, they furnish nutrition for the cells which are produced in crowds at that part of the arrangement; but when they have gained the interior of the mucous membrane, and are in the ridges between the follicles, having assumed the character of veins, they act as absorbents, conducting the material which is sufficiently digested into the portal circulation. Agreeably to this, these vessels have a larger diameter than capillaries generally. It seems, therefore, that the function of the tube is the production of cells, which, originating from germs at the bottom and sides of each tube, become perfected as they pass forward, and soon after their extension burst or deliquesce, and as the material they discharge does not possess the acid reaction, it is probably the pepsin element of the gastric juice.

The gastric juice.

It is secreted by follicles.

Constitution of the Gastric Juice of the Dog.

	Gastric juice, without saliva.	Gastric juice, with saliva.
Water	973.062	971.171
Pepsin	17.127	17.336
Hydrochloric acid	3.050	2.337
Chlorides of pot., sod., calc., amm.	4.724	6.418
Phosphates of lime, magn., iron	2.037	2.738
	1000.000	1000.000

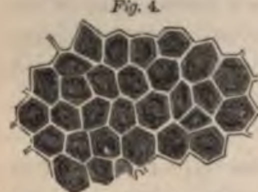
The preceding table, from Hubbenet, shows that nearly two thirds of the solid material of the gastric juice is pepsin. Exposure to a very low temperature does not deteriorate the properties of this substance, for it will resume its activity even after being frozen. But, on the contrary, a temperature approaching ebullition destroys its solvent power, and the same effect ensues when it is neutralized by an alkali.

Properties of the gastric juice.

The gastric juice acts on iron or zinc with evolution of hydrogen, an effect which the acid phosphate of lime can not produce. This seems to be decisive against the views of those physiologists who have imputed its reaction to the latter substance.

The digestive power of this juice is impeded by the presence of almost any alkaline salt. To this remark common salt offers no exception. It is owing to its alkalinity that saliva injures the digesting power of gastric juice. On the contrary, that power is very much increased by the presence of fat, which promotes the conversion of protein bodies into peptones.

Fig. 4.



Mucous membrane of the stomach magnified 70 diameters.

The mucous membrane of the stomach presents a reticulated appearance, as shown in *Fig.* 4. At the bottom of each compartment are the mouths of the gastric follicles, the size and depth of which increase toward the pylorus. Their exterior is partly covered with columnar epithelium, which extends over the intervening ridges; the residue is glandular, and continually gives origin to granules. The upper part of each follicle, as well as the entire surface of the mucous membrane, is usually covered with mucus.

Stomach follicles and tubes, their structure and functions.

Fig. 5.

Vertical section of stomach follicles and tubes magnified 150 diameters.

In *Fig.* 5 is a representation, given by Todd and Bowman, of stomach follicles and their tubes in a vertical section. The specimen is from the dog after twelve hours fasting. A represents these structures in the middle region of the stomach; B in the pyloric region; *a a*, orifices of the follicles on the inner surface of the stomach; *b b*, different depths at which the columnar epithelium is exchanged for glandular; *d*, pyloric tubes terminating variously, and lined to their extremities with columnar epithelium.

Fig. 6, A, horizontal section of a stomach follicle a little way within its orifice; *a*, basement membrane; *b*, columnar epithelium. All but the centre of the cavity of the cell is occupied by a transparent mucus, which seems to have oozed from the open extremities of the epithelial particles; *c*,

ibrous matrix surrounding and supporting the basement membrane; *d*, small blood-vessels.

Fig. 6.

Iorizontal section of stomach follicles and tubes magnified 200 diameters.

B, horizontal section of a set of stomach tubes proceeding from a single cell. The letters refer to corresponding parts. The epithelium is glandular, the nuclei very delicate, and the cavity of the tubes very small, and in some cases not visible. (From the dog, by Todd and Bowman, after twelve hours' fasting.)

Varieties of stomach follicles.

It thus appears that there are at least two distinct classes of stomach follicles, differing from each other in anatomical construction, and, as there is now reason to believe, also in physiological function, those which are near the pylorus yielding a secretion which, taken by itself, exerts only a tardy action in producing the solution of protein bodies, but those from the middle and other portions of the organ accomplishing that solution promptly. It is suspected that the acid of the gastric juice is yielded by one class of these structures, and the pepsin by the other.

Fig. 7.

The hydra.

A general idea of the structure of these secreting follicles may perhaps be obtained by likening each of them to a little glove, the hand of which opens into the stomach, and the fingers project upon the submucous tissue beneath. From the sides and tip of each finger, cells may be supposed to arise continually, and, as they are crowded forward, they undergo development, leaving the hand in a perfect condition, and deliquescing as they pass into the stomach.

Hydroid construction of the stomach.

Though we have spoken of these follicles as excavations or cup-like depressions in the mucous tissue, according to the description usually given of them by anatomists, it is to be understood that this view of their construction is philosophically incorrect, for each, instead of being a mere excavation, is truly a distinct organism, analogous in structure and many of its functions to a polype.

The hydra, a fresh-water polype, may be taken as the type of this organism. This animal, *Fig.* 7, consists of a bag or digestive sac, *a a*, ending in a cylinder, *b*, the opening to which is furnished with numerous tentacles, *c c c;* the tentacles enfold in their grasp objects on which the hydra feeds, and by their contractions carry them to the sac. Into the interior of the sac a juice exudes possessing digestive powers, and soon dissolving food.

We may therefore regard the follicular structure of the stomach as a colony of polypes, the tentacles of which are converged into a muscular tube, constituting the œsophagus. In a stomach of ordinary size there are probably a million of these organisms. Digestion is undoubtedly conducted on the same physical principles in both cases, though in the polype the food matter enters the follicular cavity of which the body of the animal consists, but in man is contained in the stomach, into which the follicles open, and pour forth their digestive fluid.

With respect to the acid constituent of the gastric juice, it appears to be hydrochloric or lactic. The latter has probably originated in the manner just described by the action of the saliva on amylaceous bodies; the former undoubtedly comes from the common salt ingested. Perhaps, under a deficiency of common salt, lactic acid discharges the entire duty. Schmidt regards the digestive principle as a conjugated acid, the negative constituent being hydrochloric acid, and pepsin being the adjunct, the compound being analogous to ligno-sulphuric acid. About twenty

Quantity of gastric juice.

parts of gastric juice are required to digest one part of dry albumen, and about 70 ounces are secreted in a day. If the hourly destruction of fibrin in average muscular action is 62 grains, about 60 ounces of gastric juice would be required each day for muscular repair. A very large demand is therefore made upon the water in the system for this use. But here the same remark is to be made as in the case of the saliva; the water, after accomplishing its object, is not lost to the economy, but is immediately reabsorbed.

Repeated passage of extraneous bodies through the stomach follicles.

It was remarked, in speaking of the salivary glands, that their secretion passes repeatedly through them, the saliva, as it exudes, being swallowed, reabsorbed, and so secreted over and over again. In these repeated passages, many salt substances, such as the iodide and bromide of potassium, will accompany it, the kidneys, however, eventually removing such extraneous bodies. In like manner, heterogeneous matters will make a repeated circulation through the gastric follicles before a final removal by the kidneys. When the latter organs have been extirpated, the constituents of their secretion, such as urea, may appear in the stomach.

On the deposit of the food in the stomach, a movement of translation is given to it by the alternate contraction and relaxation of the fibres of

the muscular coat, aided to a considerable extent by the respiratory movements of the abdominal walls. The course of this rotation commonly is, that after passing the cardiac orifice the food moves from right to left round the great extremity, and then along the large curvature from left to right, returning along the small curvature, and occupying from one to three minutes to perform this revolution, the motion continuing for a few minutes at a time.

Motions of the food in the stomach.

While this is going forward digestion is rapidly taking place, and the portions which have suffered complete action are oozing through the pyloric valve into the intestine as a semi-fluid and apparently homogeneous material called chyme. This process has fairly set in in the course of an hour, and is usually finished in about four. In consistency, color, and chemical reaction, the chyme varies with the nature of the food, its chemical constitution, and its quantity; but under common circumstances it presents the acid reaction, for it is to be remembered that the diurnal supply of hydrochloric acid to the stomach is about the fifth of an ounce. Arrived in the intestine, the chyme is pushed forward by the peristaltic movements, and soon after its appearance in the duodenum is mixed with several important fluids—the bile, which is furnished by the liver, the secretion of the pancreas, and the enteric juice which is exuding from Brunner's glands.

Formation of chyme.

The digestion of the albuminous part of the food commences in the stomach, and in that cavity advances far toward completion. The action is not merely for the purpose of bringing those substances into a state of solution in water, but also of modifying them chemically. This change is so well marked that it has been found expedient to indicate it by a designation, and hence we speak of albumen peptone, fibrin peptone, casein peptone. These peptones are, for the most part, absorbed by the blood capillaries, though a portion of them enters the circulation as a constituent of chyle. In the system, whatever their origin may have been, they seem to revert to the state of blood albumen. But, though the production of these peptones is accomplished to the extent that has been mentioned in the stomach by the gastric juice, the action is continued and brought to its completion in the small intestine by the aid of the intestinal juice. It does not appear that the large intestine participates in this duty, since portions of coagulated albumen, or of flesh introduced into it through fistulous openings, are voided through the rectum.

Summary of albuminous digestion in the stomach.

Such is the general description of the act of digestion. We have next to enter on a physical examination of what it is that really takes place in the stomach. It was formerly supposed that digestion is entirely due to nervous agency, since, if the pneumogastric nerves be divided, the process is very much interfered with.

Influence of the nerves on digestion.

But this interference takes place only in an indirect way, for the section of those nerves is attended with such a paralysis of the stomach that those movements which so well serve to mix up the food with the gastric juice, and expel it through the pyloric valve, are put an end to.

Effect of section of the pneumogastric nerves.

Bidder and Schmidt, from an examination of four dogs with gastric fistulæ, demonstrated that the section of the pneumogastric nerves does not exert that influence on the secretion of the gastric juice which had been formerly supposed, for both in quantity and composition it remained the same. Even in those cases in which both they and others have observed a diminution in its amount, the result ought, probably, to be referred to the shock given to the entire system by the severity of the operation.

The acidulating material of the gastric juice is hydrochloric acid. Is it possible by artificial mixtures containing that substance to reduce food articles to a digested condition? This inquiry introduces a description of the experimental investigations which have been made in artificial digestion.

Artificial digestion.

When water acidulated with hydrochloric acid is kept in contact with albumen, no action is perceptible at ordinary temperatures in a moderate period of time. If the temperature is raised to about 150° a slow dissolution ensues, which becomes better marked as the heat rises toward 212°.

But if to the weak hydrochloric acid thus made to act on albumen, pepsin is added, the solution takes place with rapidity at moderate temperatures. An ounce of water, mixed with twelve drops of hydrochloric acid to which one grain of pepsin has been added, will completely dissolve the white of an egg in two hours at a temperature of 100°. It acts in the same manner on cheese or flesh, these nitrogenized articles being converted into soluble non-coagulable bodies. The acid does not enter into chemical combination with the dissolving organic matter. It may be recovered from the solution by resorting to proper processes.

Artificial digestion of muscular tissue.

When striated muscular tissue is submitted to artificial digestion, it is first divided into its constituent fasciculi, and the transverse striæ then disappear, the sarcolemma being destroyed. The course of the action seems to be the same in natural digestion. In the fœcal matter, shreds of muscular fasciculi still bearing their striation may be discerned. These, having by chance escaped solution during their sojourn in the stomach, have passed through the whole length of the digestive tube unchanged.

Pepsin, preparation and properties of.

Pepsin—the substance resorted to in these experiments—may be obtained by macerating the mucous membrane of the stomach for a short time in lukewarm water. This water, along with a part of the pepsin, removes various impurities; it may there-

fore be cast away; the maceration being then continued with a fresh portion of cold water, and this being submitted to filtration, and subsequently evaporated at a low temperature to dryness, yields the pepsin as a gummy mass. From its solutions pepsin may be precipitated by corrosive sublimate or acetate of lead, and it may be separated from those combinations by sulphureted hydrogen. Wasmann availed himself of this fact to obtain it in a pure state.

Composition of Pepsin. (*From Schmidt.*)

Carbon	530.00
Hydrogen	67.00
Nitrogen	178.00
Oxygen	225.00
	1000.00

From this it would appear that it contains less carbon and more nitrogen than the members of the protein group.

A weak acid therefore possesses at a high temperature the power of bringing into a state of solution the various nitrogenized food matters, and at lower degrees fails of that property; but in the presence of pepsin the solvent powers are assumed under the latter circumstances, and therefore it is said of this substance that it replaces a high temperature. By its aid, hydrochloric or lactic acids present in the stomach reduce the food to a uniform pulpy mass—the chyme. Of all acids, these, however, alone are capable of forming digestive fluids.

Pepsin replaces a high temperature.

Formerly it was supposed that the act of digestion was simply mechanical, the food being ground down to chyme by the motions of the stomach. Reaumur's experiments showed the error of this supposition. He took small hollow silver balls, perforated with holes, and, having filled them with meat, caused them to be swallowed by a dog. When they had remained in the animal's stomach a suitable length of time, they were withdrawn by a thread which had been previously attached to them. Now if the stomach acted by a triturating or grinding power, the material within the ball would be entirely protected, but if by a solvent power exerted by the gastric juice, the digestion should at most be only delayed. Accordingly, it was found that this was what actually took place, digestion being fully, though more slowly accomplished, the action commencing on the outside of the material, and gradually reaching its centre. If the balls were kept in the stomach long enough, they came out quite empty at last.

Reaumur's experiments with silver balls.

The idea that there is something more than a simple solution of the food effected in the stomach, that some mysterious change is impressed upon it by the vitality of that organ, may therefore be abandoned. It does not appear that there is any es-

Chief object of stomach digestion is the solution of the food.

sential difference between natural digestion and the artificial imitation of it, either as respects the order of action or the final result. Moreover, the anatomical consideration that the food is yet outside the body, though it is inside the stomach, should be sufficient to remove all errors of that kind. A living surface, such as the skin, never exerts any chemical action at a distance; and the lining membrane of the stomach, both as regards its physiological origin and its anatomical relation, is nothing more than a reflected continuation of the skin. The act of digestion is completed long before the nutrient material is taken up by the lacteals and veins, and thrown into the torrent of the circulation. But then, and not till then, is the food fairly in the interior of the body.

The lacteals and veins can not exert their absorbent action on a substance presented to them unless it is dissolved in water. If not absolutely dissolved, at least it must be in that condition of minute subdivision which we see in emulsions. Though it has been stated that insoluble substances, such as charcoal, can find their way into the circulation in the solid state, there does not appear to be a sufficient weight of evidence to support such an improbability. In the economy of plants, it is a general rule that nothing can have access to the interior of their system except it be dissolved in water. All the various gases and saline substances they require are obtained in a state of solution; the former are introduced, for the most part, through the leaves, the latter through the roots. The object aimed at in the construction of the digestive apparatus of the animal mechanism is absolutely the same. Plants use as their food inorganic matter only; the chief materials on which they depend, such as the salts of ammonia and carbonic acid, are abundantly soluble in water. The ascending sap obtains the former from decaying organic residues in the ground; the atmosphere presents the latter unceasingly to the leaves; and since the economy of many plants requires earthy salts, as silicates and phosphates, which are of sparing solubility in water, the difficulty arising from that want of solubility is avoided by the introduction of an immense quantity of water, which, after bringing into the plant the needful amount of mineral material, is evaporated off at the leaves. But the food of animals is essentially organic, and this, before it can be received into their blood, must be brought into the dissolved state. It must be submitted to a preparatory operation or series of operations. However complicated these or the mechanism which accomplishes them may be, the end aimed at is clear. The action begins by the cutting, tearing, and crushing movements of the teeth, which break down all the larger portions, and carry on the process as far as it is possible by mechanical means. The stomach then continues the subdivision by chemical agency, to the end that a condition of solution may be

In plants, all nutrient material must be in solution in water.

The operations on the food are purely chemical and mechanical.

attained. Digestion is not, therefore, to vitalize the food, as the ancients supposed, nor to communicate to it any new or obscure properties; it is for the purpose of comminuting, subdividing, dissolving, or bringing it into that minutely suspended state that it can without difficulty submit to the absorbing action of the lacteals and veins. There is a complete analogy between this operation and the artificial processes to which the chemist resorts in his laboratory for the solution of various bodies. He, too, uses mechanical implements—the mortar and pestle to grind, the hammer to crush, the rasp to abrade. When these have carried the subdivision sufficiently far, he resorts to acids or other solvents, and thus breaks down the compactness of the hardest minerals, and brings them into the dissolved state. The animal world presents us with a thousand illustrations of the principles here set forth, mechanical contrivances curiously arranged. For instance, birds, whose plan of organization is such as to meet the case of locomotion through the air, could not have the anterior part of their bodies loaded with teeth, accompanied as they must have been with a powerful muscular apparatus. Such a mechanism would have rendered the animal top-heavy, and would have been totally inconsistent with flying. But, to avoid this difficulty, that which might truly be regarded as the mouth is lodged in the interior of the body, nearer the centre of gravity. It is the gizzard. Instinct teaches the bird to swallow small angular stones, and the food, rasped between powerful muscular surfaces, is soon brought into a fit condition for the action of the stomach. The chemist, too, puts fragments of glass or of quartz into the mortar in which he is conducting the reduction of a tough or resisting substance.

The first object of digestion is, therefore, the subdivision of the food. The operation begins in the mouth by a resort to mechanical implements, and when these have carried the process as far as they can, the stomach continues the duty. In its cavity, when in full activity, the temperature is 100°; a periodically increasing and relaxing motion of revolution is kept up, gastric juice exudes in definite quantity, the hydrochloric and lactic acids exert their action, and in the course of three or four hours a complete reduction is accomplished.

Regional division of the stomach for different functions.

Allusion has been made to the probability that different portions of the mucous membrane of the stomach discharge functions which are wholly distinct, one portion being devoted to the elaboration of pepsin, another to the secretion of hydrochloric acid, another to the preparation of a special mucus. This view derives considerable support from many facts in comparative physiology. In those cases in which the food approaches, in its mechanical and chemical condition, to the form which it is destined to assume as a part of the body of the animal receiving it, the stomach is simple in construction,

and is little more than a mere dilatation of the alimentary canal. But when, as among the herbivora and granivora, there is a great difference between the form of the food received and the form of the tissues to be made, the digestive sac no longer presents such a simple structure, but is parted off into distinct regions, or is actually converted into distinct organs.

Analogous arrangement in different animals.

Fig. 8.

Digestive tract of a carnivorous beetle.

Thus, in the insect digestive tract shown in *Fig.* 8, *a* is the pharynx, *b* the œsophagus, leading into a crop or insalivatory pouch, *c*, and this into the gizzard, *d*, the function of which is to rasp up and abrade the more resisting portions of the food, which, when this is accomplished, passes into the true stomach, *e*, and from thence into the intestine, *g*. The delicate vessels about *f* are supposed to be biliary tubes, and *h* glandular secreting organs.

Digestive compartments of insects.

Even in these cases of minute organization, the mucous structure remains the same as in larger animals of the same mode of life. The photographic representation in *Fig.* 9 displays the same reticulated appearance in the stomach of the carnivorous beetle as has been described in the case of that of man; and undoubtedly, with similarity of structure there is similarity in the manner of action.

Fig. 9.

Mucous membrane of the stomach of a carnivorous beetle magnified 50 diameters.

A regional division of the digestive apparatus is also presented in the case of many birds, as is shown in the photographic representation, *Fig.* 10, in which we have the digestive tract of the common fowl, *a* being the œsophagus leading into the insalivating pouch or crop, *b*, which empties into the stomach, *c*, and this into the gizzard, *d*. In the stomach, which is relatively small, the digesting material is mingled with the gastric juice before being submitted to the action of the gizzard. From the gizzard it is passed into the small intestine *f*, *f*. In the figure, *e* is the liver, *g*, *g*, the cœca, and *h* the cloaca.

Digestive compartments of birds.

Fig. 10.

Digestive tract of the common fowl.

In the ostrich, as shown in *Fig.* 11, the local distribution of the glandulæ very obviously marks out a regional distribution of function. C is the cardiac cavity, the mucous membrane of which is studded here and there with glands; G G are the surfaces of the gizzard. Among the higher quadrupeds, the evidences of a similar divis-

Fig. 11.

Interior of stomach of African ostrich.

Fig. 12.

Stomach of dormouse.

Fig. 13.

Stomach of Cape hyrax.

ion of function are presented. Thus, in the dormouse, *Fig.* 12, there are two compartments: a cardiac, C, and a pyloric, P; the same being exhibited more perfectly in the Cape hyrax, *Fig.* 13. In these cases the cardiac compartment is often lined with cuticle, but the pyloric not. An increase in the number of these cavities occurs as the food becomes more heterogeneous. In the porcupine, *Fig.* 14, there are four, and in the porpoise, *Fig.* 15, five. The stomach of

Digestive compartments of mammals.

Fig. 14.

Stomach of porcupine.

Fig. 15.

Stomach of porpoise.

Fig. 16.

Stomach of kangaroo.

the kangaroo, as shown in *Fig.* 16, possesses a multitude of these chambers or compartments, and therefore offers a good illustration of the subdivisions of stomach digestion.

Fig. 17.

Digestive cavities of a ruminant.

The case of ruminants possesses a special interest. In these there are what might be termed four different digestive chambers, as is shown in *Fig.* 17, in which *a* is the œsophagus; *b*, the inglu-

vies or paunch; *c*, the reticulum or honey-comb stomach; *d*, the omasum, manyplies, or third stomach; *e*, abomasum, reed, or fourth stomach; and *f*, the pylorus. The food, roughly triturated in the mouth, enters the ingluvies, in which it is moistened; it then passes into the honey-comb or second stomach, which likewise receives directly the water that has been taken, and, after it has been thoroughly moistened therewith, it is returned to the mouth in small portions, to undergo a more complete mastication and insalivation. Being swallowed again, it is now directed into the third stomach, from which it passes into the fourth. In this it is submitted to a true acid digestion, a gastric juice being secreted from the walls of this cavity. It is the mucous lining of this cavity which yields rennet. That these complicated motions and these successive actions of the different cavities are for the purpose of preparation for the true digestion of the fourth stomach, is clearly proved by the fact that in the calf the milk passes directly into the abomasum.

Digestive compartments of ruminants.

Since fishes and water animals generally have no salivary glands, or only rudimentary ones, some physiologists have inferred that the use of the saliva is for the commingling of the food with a due portion of water. This would reduce the importance of insalivation very greatly, and, indeed, is scarcely consistent with the elaborate mechanism which has been just described in the case of ruminant animals. It is worthy of remark that, even among fishes, there are some which exhibit a true rumination, as, for example, the carp. This is not alone for the purpose of resubmitting the food to the abrading action of the pharyngeal teeth, but likewise for commingling it with the secretion of the pharyngeal cavity.

Digestion in fishes.

In view of the preceding facts, it may be concluded that, so far from there being any thing in contradiction to the doctrine that different portions of the digestive surface of the mucous membrane of the stomach are devoted to different duties, there is strong evidence in support of its truth, derived partly from the instances furnished by comparative anatomy, and partly from the anatomical structure of the gastric mucous membrane. The four separate digesting chambers of the ruminating herbivora are merely an elaboration of the structure which is presented by an apparently homogeneous mucous surface in man. But that this mucous surface is in reality heterogeneous, and in different regions possesses different powers, is shown by the fact that at one part it presents mucous follicles, at another pepsin follicles, at another follicles for the secretion of hydrochloric acid. As we approach toward the pylorus, the existence of a new function is betrayed by the appearance of a new mechanism—the villi, which have been so well studied by Dr. Neill, and this is even indicated externally in the posterior

Regional functions of human stomach.

Fig. 18.

Posterior view of human stomach.

view of the human stomach, *Fig.* 18, showing, according to Professor Retzius, that the antrum pylori of the older anatomists is really a special compartment of the general cavity. The figure is derived from numerous examinations of the stomach in bodies of middle-aged women, and, as represented at *c c*, *d d*, indicates the antrum pylori, *a* being the œsophagus, *b* the cardiac orifice. The antrum pylori is distinguished by greater thickness of its muscular coat, more copious glandular development, and the presence of the well-known plicæ fimbriatæ. The commencement of the duodenum also forms a special rounded cavity, which Professor Retzius proposes to name antrum duodeni, characterized internally by the absence of valvulæ conniventes, and by the dense array of Brunner's glands beneath its mucous membrane. This part constitutes what has been called the fourth stomach in the porpoise and some other cetaceans. The so-called ligaments of the pylorus are connected with the formation of the antrum pylori.

Digestion accomplishes solution and metamorphosis of the food.

It has been remarked that the first aim of digestion is the procuring of the food either in a dissolved state, or, at all events, in a condition approaching thereto. But, in addition to this, profound changes in the very nature of the digested material must, in an incidental way, be constantly occurring. Thus the action of saliva is to produce lactic acid from starch, and thus, in the stomach itself, starch is transmuted into sugar. In some cases the first stage of digestion seems to be actually the reverse of what has been here set forth. Milk, when received into the stomach, undergoes coagulation, and, in like manner, so also does soluble albumen. But these are only incidental changes, the temporary solids thus produced soon liquefying as proper digestion sets in. There is reason to believe that all the protein bodies are passed into the condition of albuminose, and this though they may have been introduced in the liquid state. Even soups and broths require to be digested. A solution of gelatine, after it has been in the stomach, refuses to gelatinize, a solution of albumen to coagulate. The circumstance that gases may be evolved from digesting material, both in the stomach and intestine, is a sufficient proof that that material is undergoing

Gastric changes of the food are chiefly subdivisions and assimilation of water.

a more or less extensive change. But these changes are altogether insignificant when compared with those great metamorphoses which the nutrient material passes through after it has been absorbed from the digestive cavities; and doubtless, at the most, they are only mere subdivisions, of which the splitting of the sugar or starch atom into lactic acid may be taken as the type, or mere unions with water, of which the passage of cane sugar into milk sugar is an example.

The gastric juice, therefore, not only dissolves, but also, in an incipient and indirect manner, modifies the food. Protein bodies and gelatinous matters yield substances after its action of the same composition as their own, but with different physical and chemical properties, being readily soluble in water, and even in diluted alcohol, and not forming insoluble compounds with metalline salts. By Lehmann, who has examined these substances, they have been designated as peptones; and since they may arise without the evolution or absorption of any gas, and the quantity of sulphur they contain is the same as that in the bodies from which they were derived, he infers that the action is really an assimilation of water, the other ingredients remaining unchanged.

Production of peptones.

Turning our attention now to the origin of the gastric juice, it is interesting to observe the economical manner in which its hydrochloric acid element is managed. To the proper understanding of this, it is necessary to anticipate what will have to be more fully considered in describing the bile, a uniform ingredient of which is the oxide of sodium, or soda. The hydrochloric acid of the gastric juice and the soda of the bile are derived from the same source—common salt, which is either present in the food, or purposely added as a condiment. It undergoes decomposition easily, yielding the two products specified, that is, hydrochloric acid and soda, and is readily formed by the reunion of these substances.

Use and management of common salt.

There exists in the action of the kidneys a special provision for preventing the quantity of chloride of sodium present in the blood from rising over 41 parts in 10,000. This, of course, controls the amount diffused through the tissues. The necessity of such a regulation becomes apparent when we consider that the rate of the solubility of albumen and casein in water is governed by the presence of that substance, as is also the quickness with which the coagulation of fibrin takes place, and the repair of the waste of the muscles.

Common salt introduced into the system undergoes decomposition, furnishing hydrochloric acid to the gastric juice, and soda to the bile. Considering the large quantity of these secretions produced in a short space of time, it is clear that the drain of common salt must be great—not less than a third of an ounce a day; yet the quantities consumed, at most, are only small.

How, then, is this to be explained? Assuredly there is no other source from which these bodies can come than the one indicated—the common salt, and yet it seems to be totally inadequate.

I think that this difficulty is rather imaginary than real. Things are so arranged that a limited quantity of salt can produce unlimited quantities of gastric juice and bile; for the former, associated with the food it has digested, scarcely escapes from the pyloric valve before it encounters the bile and pancreatic juices discharging into the duodenum, and through the length of the upper portion of the small intestines these secretions, together with the food they have acted upon, are brought into complete contact. The reproduction of chloride of sodium is therefore constantly taking place in intestinal digestion, and it returns back to the system through the absorbents. Again it undergoes decomposition, its acid reappearing in the gastric juice, and its alkali in the pancreatic juice and bile. By thus using a small amount over and over again, great effects can be produced, and it is then only necessary to restore those small portions that are wasted in carrying out the general scheme.

In the low-pressure marine steam-engine we have an example of the same kind. A certain quantity of water is vaporized in the boiler and condensed in the engine; pumped back into the boiler to be vaporized, and then recondensed in the engine. Comparatively little is required to supply the wants of the machine, and long voyages can be made with only as much water as will compensate for the necessary waste arising in the working.

Stomach digestion is histogenetic; intestinal digestion is calorifacient.

For the sake of presenting the consideration of the function of digestion with clearness, it is customary to leave out of consideration the subordinate actions taking place both in the stomach and intestine. This, however, involves a certain amount of error, since respiratory or non-nitrogenized digestion occurs in the former cavity, and nutritive or nitrogenized in the latter. Nevertheless, there can be no doubt that if our view is restricted to the more imposing characters, we are justified in accepting the dogma that "stomach digestion is histogenetic or nitrogenized, and intestinal digestion is calorifacient."

General summary of digestion.

Under the most comprehensive point of view, examining the action of the entire digestive tract from the mouth to the rectum, we discover a recurrent periodicity. In the mouth, the transitory digestion taking place is wholly expended upon the calorifacient food; in the stomach it is the nutritive portion which is chiefly attacked; in the duodenum there is a return to the calorifacient, and in the cœcum of animals a resumption of the nutritive. This last is less apparent in man, for in him the cœcum exists only in a rudimentary state, represented by the appendix vermiformis.

As the alteration takes place from calorifacient to nutritive digestion, the active fluid changes its chemical relations. In the mouth and duodenum, alkaline juices are resorted to; in the stomach and cœcum, acid ones. Whenever there is an accidental inversion of these conditions, the result correspondingly changes; so when bile, which is alkaline, regurgitates into the stomach, the digestion of nutritive food is instantly arrested.

In each of these cases the object is the same: it is to obtain the nutrient material under such forms that the absorbent vessels can readily take it up; this, as we have seen, often involves a metamorphosis of the elements of the food where mechanical subdivision would be insufficient. Fibrin has to be brought into a soluble state, and, indeed, albumen itself must be modified. If it has been taken uncoagulated or glairy, it becomes opalescent, and passes into the allied form known as albuminose. In this condition it is neither precipitated by heat nor by nitric acid, though it is by corrosive sublimate. The cause of this transformation probably has reference to the relative facility with which albuminose can transude into the venous capillaries compared with albumen.

There is thus reason to suppose that the result of stomach digestion is the reduction of the various nitrogenized constituents of the food to the condition of albuminose. It is plain that fibrin must come into this or some analogous condition, for it can not be absorbed as fibrin, and, accordingly, it is found that the blood of the gastric and mesenteric veins abounds in albuminose.

Case of gelatine.

Intermediate between the classes of calorifacient and histogenetic food, belonging, by its composition and conditions of digestion, to the latter, but by the function it discharges to the former, is gelatine, a nitrogenized substance. It appears to be always derived from albumen, and any portion which may have been received in the food is never directly assimilated or used for the fabrication of tissue, but solely ministers to the production of heat. Though thus a calorifacient body, its place of digestion is the stomach. After it has suffered the action of that organ it has lost its power of gelatinizing, can no longer be precipitated by chlorine, nor give the leather precipitate with tannin. The use of it under the form of jellies, soups, etc., is always attended with the appearance of an unusual quantity of urea in the urine, and hence the administration of those domestic preparations, under an idea of their great nutritive value, is to be looked upon as only a popular error. In an indirect way, however, under the conditions of restricted diet, usually met with in the sick-room, gelatine doubtless maintains an interesting relation to the albumenoid bodies in this, that it protects them from destruction by undergoing oxidation itself, and so satisfying the requirements of the respiratory mechanism; for, were there not such a substance present to

receive the attack, the respired oxygen would rapidly bring on the waste of the proper nitrogenized tissues.

In relation to the gelatigenous tissues, it may be remarked that gelatine is not an actual constituent of them, but arises from them by boiling with water. By a like process, sufficiently prolonged, a similar substance may be obtained from cartilage, designated cartilage-gelatine, or chondrine. In these cases the material unites with water in the same manner that starch does in producing glucose.

Gelatine not an actual tissue constituent.

The food must therefore pass through various stages before it can be fitted for introduction into the circulation, and carried to all parts of the system. It is procured in portions of a suitable size either by the fingers, or, in civilized life, by resorting to artificial implements, the knife and fork. The incisor teeth next cut it up, and the molars crush or grind it, being worked for this purpose by a powerful system of muscles; meantime it is incorporated with saliva and atmospheric air. Passing into the stomach under the condition of a coarse pulpy mass, the gastric juice carries the process still farther, a more intimate disintegration of its structure ensues, and it is eventually brought into a soluble and changed form. The time required to produce this effect varies with the nature of the food. Thus it has been noticed that beef is much more quickly acted on than mutton, and mutton sooner than pork.

Digestibility of different articles of food.

Statements respecting the digestibility of different articles of food must, however, be received with many restrictions. If, as the earlier physiologists believed, the stomach was the sole digestive cavity, and the intestine only for the purpose of absorption, they would doubtless be much nearer to the truth. But when we recall that the digestion of fats does not even begin until the intestine is reached, and that the digestion of the nitrogenized substances is only in part accomplished by the gastric juice, but goes on under the influence of the intestinal juice throughout the whole length of the small intestine, we see at once how imperfect and even incorrect are the indications afforded by such experiments as those of Spallanzani, who introduced food articles into the stomach through the œsophagus in perforated silver vessels, or those of Beaumont, who availed himself of a gastric fistula. Neither can we take, in all instances, the time which an article of food will remain in the stomach as a measure of its digestibility, for this is known to vary with many conditions, as, for instance, the quantity introduced at a time, and the condition of the organ itself. As general illustrations of the digestibility of some of the ordinary elements of food, the examples, however, being more or less open to the preceding criticisms, the following facts may be offered. The white of an egg, rep-

Circumstances interfering with estimates of digestibility.

resenting soluble albumen, if introduced into the stomach of a fasting dog through a gastric fistula, will disappear in less than an hour; but if the whites of eight eggs be introduced, portions thereof can be recognized after four hours. Lehmann, who made these observations, adds that blood fibrin varies in its time for gastric solution according as it is in a finely comminuted or a massive state; in the former instance disappearing from the stomach of a dog in an hour and a half, but the same weight in the latter condition requiring almost twice the time. Coagulated albumen indicates the commencement of digestion, and even its local completion, in from five minutes to a quarter of an hour; but here again much depends on the condition of the stomach and the general state of the system, whether the animal has been fasting, and whether the gastric juice is exuding in a dilute or concentrated state.

So far as such examinations go, they do not exhibit any marked difference between albumen, fibrin, and casein. Gelatine, however, is acted on with remarkable rapidity. Beaumont observed that in an hour 150 grammes of jelly had disappeared.

Respiratory digestion, as of fat, does not begin in the stomach.

The experiments which have been made on the digestibility of vegetable food introduced through gastric fistulæ are obviously of no use, since the chief constituents thereof, such as starch and fat, are not even influenced in those circumstances until they have reached the intestine. Their passage from the stomach in this unchanged state, or changed only so far as their nitrogenized ingredients are concerned, may teach us the important fact, which should in these inquiries be always borne in mind, that disappearance from the stomach is one thing and digestion another, and that even though a substance may have passed the pyloric valve, its digestion, far from having been completed, may not as yet have commenced.

The digestion of nutritive or nitrogenized material—histogenetic digestion—is therefore carried on in the stomach mainly; and though first mechanical, and then chemical agencies are resorted to, the object is throughout the same—to obtain the food in such a divided and changed state that it can pass, dissolved in water, into the capillary vessels.

CHAPTER IV.

OF CALORIFACIENT OR INTESTINAL DIGESTION.

Nature of Intestinal Digestion.—Structure of the Intestine.—Digestive Fluids of the Intestine.—The Pancreatic Juice.—The Enteric Juice.—Juice of Lieberkuhn.—Secretion of Peyer's Glands.—Bile.—Digestion of the Carbohydrates and Hydrocarbons.—Properties and Varieties of Lactic Acid.—Doctrine of the Effects of Acidity and Alkalinity of the Digestive Juices.—Illustration of Intestinal Digestion from the making of Wine.—Making of Bread.—Influence of Heat over Ferments.—Comparison of Gastric and Intestinal Digestion.—Changes of the Intestinal Contents.—The Fæcal Residues.

After the chyme formed in the stomach has passed through the pyloric valve into the small intestine, the influence of the gastric juice continues for a certain time, even after the bile and pancreatic juices have been reached. Since their action must be necessarily, in the first instance, superficial, the interior of the mass is still undergoing stomach digestion.

But, setting aside this incidental result, which at the most can not be of long duration, the digestive operation taking place in the part of the intestinal tract now under consideration is directed to the heat-making food.

Nature of intestinal digestion.

The organ in which calorifacient digestion takes place may be described as a tube bounded by two valves, the pyloric above and the ileo-cœcal below. Its length may be estimated at about twenty feet. The digestive surface, making a due allowance for its increase by reason of its valvular structure presently to be described, can not be much under 3500 square inches. The dimensions of the calorifacient digesting surface are therefore far greater than those of the nutritive.

Structure of the intestine.

The interior and acting portion of this tube presents two different systems of apparatus, and is occupied in the discharge of two totally distinct functions, digestion and absorption. It is, perhaps, this double duty which demands so extensive a surface, and not the necessities of heat-making digestion alone.

Double apparatus of intestine.

Like the stomach, this tube consists of three coats—a serous, a muscular, and a mucous. The latter is gathered up in its interior into numberless projecting folds—the valvulæ conniventes. These serve to increase the surface to which the food is exposed, and perhaps afford a mechanical obstacle to its passing too quickly forward. They tend also to break the continuous motion, and bring the interior parts of the chyme to the surface. The onward move-

Action of the valvulæ conniventes.

ment is of course due to the pressure exerted conjointly by the straight and circular fibres of the muscular coat. Anatomists divide the tube into three portions—the duodenum, jejunum, and ileum.

Fig. 19.

Posterior view of the duodenum.

In *Fig.* 19 we have a posterior view of the duodenum, *a* being its superior or pyloric extremity, *b* the middle portion, *o* the jejunum, *d* the gall-bladder, *i* the cystic duct, *p* hepatic duct, *c* the ductus communis, *m* pancreatic duct.

Soon after the chyme has escaped through the pyloric valve into the duodenum, it comes under the influence of the bile and pancreatic juices, which are sometimes discharged upon it at a common point, and sometimes at a little distance apart. Almost simultaneously it is submitted to the mechanical action of the valvulæ conniventes, which make their appearance in the vertical portion of the duodenum, and continue in large numbers until within the last two or three feet of the end of the tube. As the intestine is distended, these project with a certain degree of turgidity, and accomplish their mechanical object.

Digestive fluids of the intestine.

But, besides the pancreatic and biliary fluids, there are other juices thrown upon the passing chyme—the enteric juice, which comes from Brunner's glands, and a liquid oozing from the follicles of Lieberkuhn. Moreover, the organisms known as Peyer's glands are affecting the contents of the tube. Of each of these it is necessary therefore to speak.

1st. The pancreatic juice, secreted by the pancreas, an organ bearing a resemblance in its anatomical construction to the salivary glands, and hence usually regarded as one of that group. The juice itself is analogous to saliva, being viscid, and in its reaction alkaline: its specific gravity is about 1.008. Alcohol coagulates it. It is said to contain no sulphocyanide nor any suspended particles. It acts upon starch even more energetically than saliva, transmuting it into sugar and lactic acid, and upon fats by forming them into an emulsion, so that they are readily absorbed. This has been found to take place in artificial experiments by submitting fat substances to the juice at a temperature of 100°.

Pancreatic juice, constitution and properties of.

Constitution of Pancreatic Juice of Dog. (From Schmidt.)

Water	900.76
Organic matter	90.38
Inorganic "	8.86
	1000.00

As would be inferred from the difference of emulsifying power between the saliva and this juice, its organic matter differs from ptyaline. It is estimated that the standard secretion of it is from five to seven ounces per diem.

The action of the pancreatic juice appears to be limited to the upper half of the intestine, for it is in that region only that butyric acid is developed from butter.

Enteric juice.

2d. The enteric juice is secreted by the organs known as Brunner's glands, the structure of which has a certain analogy to the preceding, and, like it, these doubtless belong to the salivary group. Brunner's glands occur chiefly in the upper part of the small intestine, presenting themselves in the submucous tissue thereof as little bodies, commonly compared by anatomists to hemp-seeds. They consist of lobules with ducts communicating with a common outlet. Their secretion possesses a more energetic power when mixed with bile and pancreatic juice, than the pancreatic juice alone, in producing fatty emulsions.

In the opinion of Bidder and Schmidt, the intestinal juice, which they describe as being invariably alkaline, not only metamorphoses starch as rapidly as the saliva or pancreatic juice, but also exerts as powerful an action on flesh, albumen, and other protein bodies as that which occurs in the stomach itself.

Fig. 20.

Diagram of Brunner's glands.

In *Fig.* 20, which is a half diagram of one of these glands, *a a* represents the mucous surface of the intestine, and *b* the lobulated gland, discharging its secretion through a common duct.

Secretion of follicles of Lieberkuhn.

3d. The secretion of the follicles of Lieberkuhn, which, as shown in *Fig.* 21, are straight, narrow cœcal depressions of the mucous membrane, found all over the small intestine, and in a general manner analogous to the tubular follicles of the stomach. Their interior is lined with columnar epithelium, and in depth they are equal to the thickness of the mucous membrane, their closed ends being therefore in contact with the submucous tissue, and their mouths opening into the intestine. In a state of health they contain a clear mucus-like secretion. In inflammations of the part they are filled with a more opaque, whitish liquid. From their resemblance to the follicles of the stomach which secrete pepsin, it may be presumed that they possess a somewhat similar function; but in the stomach, the resulting secretion is brought in relation with acids; in the

Fig. 21.

Diagram of follicles of Lieberkuhn.

intestine, with alkaline bodies; and hence the physiological action may differ in the two positions, though the structure and primary function may be the same.

Secretion from Peyer's glands.

4th. The secretion of Peyer's glands. These may be described as circular spots, of a whitish color, and about the tenth of an inch in diameter, constituting glandular patches full of cell germs, but without any excretory duct opening into the intestine. It is supposed that they discharge their contents by rupturing at a certain stage of their development. The solitary and agminate glands appear to belong to the same physiological group.

Fig. 22.

Peyerian glands.

The two conditions of the Peyerian glands are shown in *Fig.* 22, the right one being empty, its contents having been discharged, the left one still full. By some it is denied that these bodies are connected with intestinal digestion. The facts that vascular loops pass into their granular contents, and that the lacteals bear a definite relation to them, seem to indicate that they are rather portions of the absorbent mechanism.

The bile.

5th. The bile. Of this it is not now necessary to give a detailed description, since that will occur more appropriately in treating of the functions of the liver. For the present purpose, it is sufficient to state that bile is a greenish-yellow liquid, of bitter taste and alkaline reaction. It is soluble in water, changes with rapidity under the influence of the air, or even spontaneously. Its specific gravity is about 1.028. An ultimate analysis of its organic material shows C_{76}, H_{66}, O_{22}, N_2, with sulphur. Its aspect is therefore that of a hydrocarbon, and it stands in strong contrast with the nitrogenized bodies. It is a significant fact that, even in the lower tribes of life, it is uniformly discharged into the upper part of the intestine. Bidder and Schmidt estimate the diurnal quantity of bile at 54 ounces, containing 5 per cent. of solid matter; they also give the following table of the diurnal amounts of the various digestive fluids secreted by a man of the standard weight, 140 pounds:

Diurnal Amount of Digestive Secretions.

Saliva............	3.30	lbs.,	containing	solid	matter	1.	per cent.
Bile..............	3.30	"	"	"	"	5.	"
Gastric Juice......	14.08	"	"	"	"	3.	"
Pancreatic Juice...	.44	"	"	"	"	.1	"
Intestinal Juices...	.44	"	"	"	"	1.5	"

The bile does not appear to exert any agency in effecting the digestion of either nitrogenized or amylaceous bodies. The period of its max-

imum production, which is 13 or 14 hours after a meal, does not coincide with the period of most energetic digestion.

With these statements of the nature of the various juices which pass into the small intestine, we may proceed to investigate the phenomena of the digestion carried on in that tube.

Emulsifying power of pancreatic juice.

In 1832, Dr. Bright, to whom medicine is so much indebted for his discoveries in relation to the pathology of the kidney, published three cases of disease of the pancreas, attended by the appearance of a large quantity of fat in the fæces, and drew the inference that in such morbid states the fats are imperfectly digested. More recently, M. Bernard has published experimental evidence to prove that the digestion of the fats consists in bringing them into the condition of an emulsion, and that the pancreatic juice accomplishes this object.

Whatever influence the pancreatic and enteric juices can exert on starch and oil outside of the body, in artificial experiments, they undoubtedly exert it in the small intestine as long as the temperature is the same. On starch, the action, as has already been stated, is to effect its conversion into sugar, and then into lactic acid. The oils are turned into emulsions. The constitutional relation between starch and lactic acid is such, that if, in presence of water, one atom of the former be equally and systematically split or divided into two portions, those portions are atoms of lactic acid. And since this substance contains no nitrogen, its oxidation either artificially or in the interior of the system gives origin to carbonic acid and water—bodies which can at once be removed by the action of the skin, or the lungs, or the kidneys.

Subdivision of starch into lactic acid.

Respecting the digestion of the carbohydrates—cellulose, gum, starch, and the different kinds of sugars, it may be remarked, that cellulose, of which the pith of elder is an example, and which occurs in a pure form in Swedish filtering-paper, not only resists, in artificial experiments, the action of the digestive juices, but also it would appear to do so naturally in the higher tribes, and hence it is abundantly found in the excrement of the herbivora. To this statement, perhaps, however, the case of the beaver affords an exception, there being reason to suppose that this animal possesses the power of digesting cellulose.

Digestion of the carbohydrates.

Digestion of cellulose.

There can be no doubt, moreover, that many insects have the same power, for chitin, which may be obtained from their wing-cases, and which retains the appearance of the structure of the part, may be considered as cellulose united with a nitrogenized body, having the constitution of insect muscular fibre. This substance not only constitutes the skeleton of insects, their scales, hairs, and enters into the construction of their tracheæ, but even forms one of the coats of their intestinal canal. Since

it does not appear that they can metamorphose other carbohydrates into this body, we may infer, as would indeed seem probable, considering the nature of the food of many of them, that they can digest woody fibre. The digestive apparatus of man, however, can not exert such a power.

Neither does it appear that gum undergoes either digestion or absorption. In artificial experiments it also resists the action of digestive fluids, and is not changed when present during the fermentation of other bodies, even though its exposure thereto be continued for several days. Administered to animals, it is almost entirely voided with the excrement. Thus Boussingault, having given to a duck fifty grammes of gum-arabic, obtained forty-six grammes from the excrements in nine hours. In an experiment upon an old rabbit, to which, with a diet of cabbage-leaves, ten grammes of gum-arabic were daily given by Lehmann, the gum being administered in solution in water by injection into the stomach, no trace whatever of gum could be detected in the urine, none in the chyle of the thoracic duct, and none in the blood, but it was easily enough recognized in the excrement. From this he infers that the preparations of gum, which are such favorite medicines with some physicians, yield to the animal organism only an extremely small quantity of material of a nature to support the respiratory process, and that their uses, if they are of any use, can be merely negative in acute diseases.

Digestion of gum.

Of the carbohydrates, starch is perhaps the most important, occurring as it does in abundance in vegetable food. It can not be made use of in the system without first being transmuted into dextrine, sugar, and eventually lactic acid, these changes being greatly expedited if it has been previously prepared by boiling in water, or other equivalent operations of cooking. The saliva commences the action, which in man is even prolonged in the stomach, and in the herbivora still more decisively in the paunch, in birds in the crop. On gaining the stomach, the farther transmutation of the starch is arrested by the gastric juice, but after reaching the duodenum it is resumed with greater energy than ever, under the influence of the pancreatic juice. Reaching the ileum, the intestinal juice continues the action, though with less vigor. In this passage to the large intestine, the starch is gradually assuming the condition of dextrine and sugar, the former substance passing into the latter with such facility that it can only be recognized transiently. Doubtless the sugar thus arising is in great part directly absorbed, though some, before the cœcum is reached, is transmuted into lactic acid, and other portions, after passing through the ileo-cœcal valve, into butyric acid.

Digestion of starch.

From what has been observed respecting starch, it may be inferred how important sugar is, since through the condition of sugar alone is starch available for the uses of the system. It is to be rec-

Digestion of sugar.

ollected, however, that sugar itself is only an intermediate or transitory stage, through which the carbohydrate is passing, a consideration which explains the circumstance that it does not occur even in the portal blood to such an extent as might be expected, nor yet in the chyle. Some have been led to infer from these facts that this substance, like gum, is in reality only very tardily absorbed, an opinion which they suppose to be strengthened by the circumstance that glucose or any other kind of sugar, introduced into the jugular vein, runs through the course of the circulation, and is secreted unchanged by the kidneys. But it is to be remembered that portal blood is very different from the proper systemic blood, and that there are many changes, beyond all question, which can take place with rapidity in the former, but which do not take place in the latter.

Sugar, whether it has been received as an ingredient of the food, or arisen from the metamorphosis of starch, is, as we have said, only a temporary form, which passes quickly onward to the state of lactic acid. To this we must impute the acid reaction which is observed throughout the length of the small intestine, and which can not be attributed to the gastric juice, a reaction occurring in spite of the alkalinity of the bile and pancreatic secretion. This pushing of the carbohydrate forward to the state of lactic acid is very generally imputed to the intestinal juice, which greatly re-enforces the power of the saliva and pancreatic fluid; some have even supposed that the bile aids in producing this effect. Of this, however, there is no satisfactory proof.

From the experiments of Von Becker, who injected saccharine solutions at intervals of a quarter of an hour into the stomach of rabbits, it was found that 4.5 parts of sugar were absorbed each hour for every 1000 parts weight of the animal. Whatever may have been the form of sugar administered, as, for instance, cane-sugar, it quickly passes into the condition of glucose in the intestine, and from that to lactic acid. Thus sugar of milk may be traced in an hour as far as the cœcum, communicating to the contents of the small intestine an intense acid reaction.

Production and properties of lactic acid.

Since lactic acid discharges very important offices in the animal economy, it may be worth while to observe its properties, and the circumstances under which it is produced. Very many liquids containing organic matter yield it abundantly: thus it is found in *sauer kraut*, a preparation of cabbage. It is, however, more conveniently obtained from milk, and hence the term lactic acid. The diluted solution obtained from this source, being concentrated by evaporation, furnishes a sirupy liquid, heavier than water, having an intensely sour taste, a great affinity for water, and therefore attracting it from the air, and dissolving freely in it. With metallic oxides it forms soluble salts, and in the concentrated sirupy state has the remarkable con-

stitution that it contains six atoms of each of its elements, carbon, hydrogen, and oxygen.

The production of this acid in organic substances is very common. It depends on the same principle as presented in duodenal digestion, which it therefore very strikingly illustrates. As an example deserving of attentive consideration, its development in milk may be offered.

When milk is exposed to the air it eventually turns sour, the sourness being due to the appearance of lactic acid. In its sweet state, the milk may be regarded as consisting of casein, or the curdy principle, a substance belonging to the protein group, insoluble in pure water, but abundantly soluble if a little free or carbonated alkali be present; of milk sugar, dissolved, and of butter held in suspension in water. The action taking place during the souring is as follows: Under the influence of atmospheric oxygen, which for this purpose must have access, the nitrogenized principle, the casein, begins to change, and, for reasons presently to be more particularly examined, impresses a change on the sugar, splitting its atom so as to give rise to the production of lactic acid. As this forms, it renders the casein insoluble, and the milk begins to coagulate, to prevent which a little carbonate of soda may from time to time be added. All the sugar originally present in the milk is soon acidified, but a much stronger solution can be made by adding more milk sugar as the process of exhaustion goes on, and the change can be thus kept up until the casein itself is quite consumed.

Production of lactic acid from milk.

On examining this process critically, we observe that every thing depends on the change occurring in the nitrogenized principle, the casein. This, under the circumstances, takes on an incipient oxidation, and compels the sugar atom so to divide as to give rise to the production of lactic acid. This ceases the moment the casein ceases to change, and recommences the moment the casein is permitted to reoxidize. The destruction taking place in the casein is propagated to the sugar, the physical peculiarity being that the atom of sugar is merely divided, fissured, or split, and gives rise to the production of lactic acid, and no other substance. The whole process is therefore essentially one of subdivision, a conclusion which should be carefully borne in mind in applying these experimental principles to the physiological function of digestion. So far as the result is concerned, the two cases are the same.

Many other organic liquids furnish similar illustrations. Thus, in the operation of making starch for commercial purposes, considerable quantities of that substance are turned into lactic acid, constituting what the manufacturers term *sour liquor*. Nor is it even requisite that so much water should be present as to give the liquid condition; for if wheat flour be made into a paste, and kept for

Production of lactic acid from starch.

some days in a warm place, its gluten induces such a change that the starch turns into lactic acid, and the paste becomes sour.

Of lactic acid there are two kinds; that derived, as hereafter stated, from muscle juice, is the alpha lactic acid, and that from the fermentation of sugar the beta lactic acid. As it occurs in the gastric juice, associated with or replacing hydrochloric acid, it is of the beta variety. Whatever may have been the source of this portion of it, whether it has been derived by gastric secretion or through the transmutation of amylaceous food by the saliva, its abundant occurrence in the contents of both the small and large intestines, in which it is recognized by the peculiarities of its zinc and magnesia salts, confirm the conclusion that in this case, at least, the beta form arises from the operation of the digestive juices.

Alpha and beta lactic acid.

Lactic acid undergoes rapid absorption through the intestine, and is as rapidly disposed of in the system. Thus Lehmann found, after taking half an ounce of dry lactate of soda, that in thirteen minutes his urine had become alkaline. On injecting the same salt into the jugular vein, it appeared in from five to twelve minutes as carbonate of soda in the urine.

Berzelius first discovered the existence of lactic acid in the juice of the muscles. Liebig showed that, in quantity, there is more present in this source than is sufficient to neutralize the alkali of all the other liquids or juices of the body. Muscle lactic acid is removed away with rapidity by the lymphatics. Berzelius concluded that its quantity increases in proportion to the exercise the muscle has undergone; and this would lead to the inference that it is one of the chief products of muscular waste; for it is not to be supposed that its appearance in muscle juice is because those organs attract it from the blood, in which it pre-exists, derived, perhaps, from the transformation of amylaceous substances in the intestine, for the muscles of the carnivora yield as much of it as those of the herbivora; and though it can not be artificially made directly from albuminous material, yet it would seem that, with urea and ammonia, it might arise from the breaking up of creatine. From glycerine lactic acid may be also developed. Whenever an excess of it is produced in the system, either by muscular action, unusual diet, or imperfect oxidation in the blood, it may be detected in the urine. Under ordinary circumstances, doubtless, very large quantities of it are destroyed in the circulation, giving rise to the production of carbonic acid and water with a disengagement of heat.

Production of lactic acid by the muscles.

We can not here fail to remark how the process of comminuting the food is carried forward to such an extent that the absorbent vessels are able to take it up. The action first begins, as has been shown in detail, by cutting and crushing implements,

These digestive operations are subdivisions.

the teeth, and when these have carried the subdivision as far as mechanical means can, it is continued by chemical agents. Upon these principles, the pancreatic juice divides starch into lactic acid in duodenal digestion—a product which, without difficulty, finds its way at once into the system.

Digestion of fat.

Besides starch and sugar, there is another group of bodies belonging to the class of calorifacient food, which, in the case of carnivorous animals, seems to be exclusively employed. The fats and oils constitute this group.

The action of the pancreatic and enteric juices upon these bodies, in bringing them into the condition of an emulsion, has already been stated. That this occurs in the intestine appears from the fact that if the pancreatic duct be tied, no emulsion forms, and the chyle in the lacteals is limpid instead of being milky. In the rabbit this duct opens much lower in the intestine than the biliary, and it is observed that it is only after the food has passed that point that it becomes emulsioned. The place for pancreatic digestion seems to be very constant in tribes that are far apart in habits of life. Thus, in fishes, the pancreas consists of a coronet of cœcal tubes, surrounding the pyloric extremity of the intestine, each opening into that organ by a separate mouth.

The fats reach the duodenum without undergoing any change. There, under the influence of the pancreatic juice, they become subdivided into extremely minute portions, which, absorbed by the lacteals, give to the chyle its characteristic aspect. Beyond this condition of subdivision no other change is thus far impressed, the fat of the lacteals being absolutely the same as that of the chyme. To the introduction of fat into the lacteals, the presence of bile seems to be necessary, or, if not absolutely necessary, absorption is greatly facilitated by it.

Bernard's doctrine of the effect of acidity and alkalinity in the digestive juices.

The gastric and pancreatic juices stand in a remarkable relation to one another, the former being an acid liquid, having the power of bringing into a state of solution nitrogenized bodies, such as fibrin; the latter alkaline, without action on nitrogenized bodies, but operating energetically on starch, sugar, and oils. From this it might be supposed that the intrinsic qualities of these juices are different, and that they act in this manner because of a special dissimilarity of constitution.

Attempts have been made to prove that this difference of action depends wholly on the chemical relations of the juice itself. If pancreatic juice or saliva be purposely acidulated with hydrochloric acid, it is said that it loses at once the power of acting on calorifacient food, but can bring about the solution of the histogenetic. On the other hand, if gastric juice be rendered alkaline by admixture with soda, it no longer dissolves fibrin or coagulated albumen, but gains the power of acting on starch and sugar. Since, then, it thus appears that the same organic body

becomes endowed with one or other of these properties, according as it is acidulated or alkalinized, the function of digestion is presented to us under a simple aspect. It is upon these principles that we may explain the fact that the presence of bile in the stomach suspends or arrests the digestion going on in that organ.

Though the views here expressed are such as are received among many chemists, yet it is still open for consideration whether the nature of the result which is reached in these cases does not, to a great extent, depend upon the nature of the organic changing body, the ferment, which first sets up the action. Many circumstances would lead us to infer that this must be the case, and that, as with differences of temperature, so also with these differences, the final result may present distinct variations, though they may be within a certain range or limit. Thus, though the saliva and pancreatic juice are both alkaline, and both impress in a general way the same digestive change on starch and sugar, a minute examination of the results of their action would doubtless lead to the detection of shades of difference—variations which could only be attributed to the difference between the active organic principle of the pancreatic juice, and ptyaline, the corresponding principle of the saliva.

The nature of the organic ingredient more important than the reaction.

The imputed control which the alkalinity or acidity of the digesting juices exerts in determining the result, illustrates the important function discharged by common salt, which furnishes to the juices of the stomach and intestine the characteristic ingredients they require by breaking up readily into hydrochloric acid and soda, and re-forming at once whenever these materials are brought in contact. There is, therefore, an important reason for the instinct which animals display in resorting to the use of this substance, as in the buffalo licks at the West, and the necessity which men experience to add it as a condiment to their food. But though, by furnishing an acid or alkali, as the case may be, it determines the nature of the work which the secreting juices perform, it is not to be regarded as the prime mover of the change. It guides rather than works. The efficient principle bringing about digestion appears always to be a nitrogenized body, acidulated, perhaps, for the production of one duty, and rendered alkaline for the performance of another.

Relations of common salt in digestion.

Directing our attention now more particularly to the phenomena displayed by such a changing nitrogenized principle, the following illustrations will serve to show that there is nothing mysterious in its operation. Out of many cases which might be selected, those now to be offered are more particularly interesting, since they refer to substances extensively used in the diet of man.

First, of wine. A grape, if perfectly sound, will keep for a consider-

Illustration from the making of wine.

able length of time without undergoing any change; but if a puncture be made in it to give the air access, it rapidly deteriorates. The precise change taking place is perhaps better understood by observations on the expressed juice of this fruit. If grapes be pressed beneath the surface of quicksilver, and the juice be collected in an inverted jar, without ever coming in contact with the atmospheric air, it may be kept for a long time without any apparent change; but if a small quantity of air, or only a single bubble of oxygen is permitted to enter the jar, and the temperature is that of a summer's day, an intestine commotion or fermentation at once ensues, carbonic acid escapes, alcohol arises in the liquid, and the sugar which was in the grape-juice disappears. But the quantity of sugar thus capable of being destroyed is limited, and a point is eventually reached at which no more sugar can be decomposed, and no more carbonic acid set free.

The juice of the grape contains a nitrogenized principle resembling albumen. It is this which is in reality the active body. So long as oxygen is excluded, this nitrogenized substance remains unaltered, but the moment the air finds access, a change begins. The sugar which is present in the juice becomes involved in the movement going on, which is propagated by degrees to all its atoms, dividing each into two well-known and well-marked bodies. The period at which no farther change takes place in portions of sugar which may have been purposely added is when the nitrogenized principle has disappeared.

Carbonic acid and alcohol are the two substances arising in this decomposition. Their mode of origin is obvious when it is understood that one atom of sugar can be so divided as to yield four of carbonic acid and two of alcohol. In this artificial instance, the subdivision is even more complex than that which occurs in duodenal digestion, in which the sugar atom is subdivided into two equal and symmetrical parts, two atoms of lactic acid. In the following formulas, (1) represents the case of vinous production, (2) that of duodenal digestion:

$$(1) \; . \; . \; . \; . \; . \; C_{12}\, H_{12}\, O_{12} = 4\, (CO_2) + 2\, (C_4\, H_6\, O_2).$$
$$(2) \; . \; . \; . \; . \; . \; C_{12}\, H_{12}\, O_{12} = 2\, (C_6\, H_6\, O_6).$$

Illustration from making of bread.

Second, of bread. If, in the preceding case, a transmuting nitrogenized body breaks the sugar atom so that alcohol is one of the products, and upon this principle all wines and intoxicating liquors are made, the instance now presented is of far more interest to the well-being of man. The use of wine undoubtedly adds not only to social enjoyment, but sometimes conduces to health—a benefit, alas! often attended with a thousand ills. Not so with bread, emphatically and truly described as the staff of life.

The making of wine and of leavened bread are two of the oldest chem-

ical processes. Their origin is lost in a remote antiquity, and so universally are their benefits acknowledged that their use is diffused all over the world.

Experience proves that the best bread is made from fine wheaten flour, mixed into a paste with a due proportion of water. A certain quantity of a nitrogenized substance undergoing incipient oxidation, termed yeast, is added, and the whole submitted to a gentle temperature. All flour contains a small quantity of sugar; on this the yeast immediately acts, dividing it, as in the former case, into carbonic acid and alcohol. If enough sugar is not present, more under the circumstances is formed from starch. The acid gas, as it is set free, can not extricate itself from the surrounding dough, but expands into a thousand little vesicles or bubbles, which give that peculiar porosity for which this kind of bread is so highly prized. At this period, before baking, the other substance which has arisen from the destruction of the sugar—the alcohol—is contained in the dough, and is expelled therefrom along with the excess of water by the high temperature of the oven, which also, by increasing the expansion of the included gas, adds to the porosity of the bread. In some baking establishments arrangements have occasionally been made to condense the alcohol as it rises from the bread. The good and evil of life are often closely intermixed. The advocate of total abstinence from alcohol may with reason look upon half-baked bread distrustfully. The enemy is lying in ambush for him.

On some occasions, instead of using yeast, a piece of leaven, that is, dough in a state of incipient putrefaction, is employed. The mode of action is, however, the same. The use of this material well illustrates the progressive nature of these changes, and how the action gradually passes from point to point of the entire mass. It is written, "A little leaven leaveneth the whole lump."

These actions, like those of digestion, are subdivisions.

In the cases here presented the action is one of subdivision. A complex atom has its constitution broken up, and is separated into distinct parts. When such a change is once commenced in a mass, there is a liability for the whole to become involved, just as, when we ignite one point in a pile of combustibles, the fire spreads throughout; or as, when on one part of a piece of fresh meat a small portion in a putrescent state is laid, the corruption, with measured rapidity, proceeds from part to part, until the whole is decayed. One after another, the particles submit in succession.

Influence of heat over these subdividing actions.

Over all these subdividing actions heat exerts the most extraordinary influence, so that for a given effect to be produced it is absolutely necessary that a given temperature should be maintained. Thus, if we take the saccharine juice of almost any kind of fruit, and cause it to be acted on by a changing nitrogenized body,

it will yield, as just stated, alcohol and carbonic acid so long as the temperature ranges about 75°; but, every thing remaining the same, if the temperature be raised to 100° or 120°, neither alcohol nor carbonic acid is formed, but in their stead other products arise, such as lactic acid, gum, and manna. Though, therefore, decomposition will go on throughout all this range of temperature, the products will vary very much, alcohol being formed at a low, and lactic acid at a high degree.

Again, the decomposition of milk furnishes a very instructive instance. When the temperature ranges from 50° to 75°, the liquid turns sour, owing to the formation of lactic acid; but if the temperature is over 90°, the products are different, for now a true vinous fermentation sets in, alcohol and carbonic acid appearing. It is on this principle that the Tartars make an intoxicating liquid from mare's milk. The fermentation of milk, therefore, yields lactic acid at a low, and alcohol at a high degree.

On comparing these illustrations, the results stand in direct contrast, but both show the great influence which a specific degree of heat exercises over such subdivisions; and, as a consequence of this principle, which obtains equally in the physiological case, we recognize the necessity of maintaining the cavity of the stomach and intestine uniformly at a temperature which is fixed, otherwise there would cease to be any uniformity in the subdivision of the food, occasioned by the digestion there going on. These principles, moreover, lead to the explanation of the action of such stimulating substances as alcoholic liquids, pepper, etc., which at once determine a local elevation of temperature; they also explain the injurious effects which may ensue from intemperate draughts of ice-cold water.

A nitrogenized substance, in a state of change, can thus bring about a definite action on fibrin, coagulated albumen, or casein in the stomach, or on starch in the intestine, so long as a temperature of 100° is maintained, but in every known instance this transmuting power is totally destroyed by exposure to a very low or very high degree of heat. Large masses of animal matter—whole carcasses—may be preserved for many centuries unchanged if the temperature is kept down to 32°. A striking example of this occurs in the case of the extinct elephants which are occasionally thrown on the shores of the Polar Sea from icebergs, in which they have been entombed for many thousand years, their flesh remaining in a perfectly fresh and undecayed state. And as respects a high temperature, an exposure to 212° totally destroys the power. On this principle, all kinds of meat or vegetable substances may be indefinitely preserved. If such are inclosed in metallic canisters, so as totally to exclude the atmospheric air, and exposed to a bath of boiling water, they may then be carried around the world without undergoing any change.

Loss of power in ferments by a high temperature.

One of these illustrative cases still remains. It belongs to the class of changes now under consideration, and deserves a prominent examination from its connection with duodenal digestion. It is the production of fatty bodies from starch and sugar.

Physiological considerations assure us that there are circumstances under which oils and fats can be formed from starch and sugar in the system. Animals can be fattened by feeding on potatoes, or other such food, in which the quantity of oil is quite insignificant. Bees can make wax, which strictly belongs to the group of fats, though they are fed on pure white sugar.

Production of fats from carbohydrates.

Such results can be artificially imitated. If a strong solution of sugar be mixed with a small quantity of casein and powdered chalk, and exposed to a temperature of more than 80°, carbonic acid and hydrogen are evolved, and butyric acid forms as the butyrate of lime. This acid substance is a colorless oily liquid, having the odor of rancid butter, in which indeed it exists.

From a review of all the preceding facts, we may conclude that a nitrogenized substance secreted by the follicles of the stomach, and undergoing incipient oxidation, acidulated with hydrochloric acid obtained by the decomposition of common salt, or with lactic acid produced by a continuation of salivary digestion, has the power of dissolving coagulated albumen, and generally those articles of food which belong to the nitrogenized class; that this goes on in the stomach, it being the function of that organ to effect the digestion of this kind of food, and thereby contribute to the general nutrition of the system. The muscular tissues are supplied from this source, and by the stomach their waste is repaired.

Contrast of gastric and intestinal digestion.

Another and distinct digestion takes place in the intestine, commencing immediately after the food gains the duodenum. It too is brought about by the action of a special liquid, a mixture of the pancreatic and intestinal juices. The chemical reaction of this juice is alkaline; in this respect it is therefore antagonistic to the gastric juice. This quality is due to the soda it contains, a substance derived co-ordinately with hydrochloric acid from the decomposition of common salt. The digestion of starchy and saccharine bodies is thus effected by dividing them so as to produce lactic acid.

This done, common salt is reproduced by the commingling of the gastric, biliary, and pancreatic products together. The salt is carried by the absorbents into the interior of the system, to be again decomposed.

Moreover, the pancreatic and enteric juices reduce the oleaginous and fatty bodies to the condition of an emulsion, or, if they be not present in the food, give origin to them in the way just described.

The reaction of the intestinal contents not only differs in different por-

Successive changes in the transit through the intestine.

tions of the tube, but in the same region, in different parts of the mass, its exterior may be alkaline, its interior acid, or the converse. The acidity which has been imparted by the gastric juice seems generally to have disappeared some time before the large intestine is reached. In this an alkaline reaction is observed. The causes of this prolonged acidity are very various. In part it depends on the nature of the food, in part upon the gastric juice, as has just been stated, and in part upon the production of lactic, butyric, and other acids. The resinous ingredients of the bile may be detected as far as the lower extremity of the ileum. Glucose, originating in the action of the pancreatic and intestinal juices on starch, may be recognized throughout the whole length of the canal, but that which has been introduced in the food seems to be absorbed in the stomach itself; thus, in milk-fed animals, sugar does not appear to descend beyond the jejunum. The transmutation and reabsorption of biliary matter commences in the small intestine and proceeds continuously, so that by the time the middle of that portion of the tube is reached, half the bile is gone.

Since the intestinal absorbents can only take up a definite proportion of fat, it might be expected, as is really the case, that after an unusually fatty diet, fat substances will be found in the excrement. Indeed, a certain small proportion always so occurs.

Salts of the intestine.

Of the salt substances usually occurring in the food, most disappear during their passage through the intestine, and hence but little is found in the fæces; more particularly is this the case with those of a very soluble kind. Of the sulphates and chlorides of the food, not even a trace may occur in the excrement. If these substances should not be required for the uses of the system, they are promptly removed by the kidneys, and in the same manner are disposed of any abnormal salt substances which may have been purposely administered, as, for instance, iodide of potassium.

Gases of the intestine.

The gaseous contents of the intestine originate in part from the air that has been introduced during the mastication of the food, in part from fermentative processes occurring after certain articles have been used which are only imperfectly digested, and in part from the endosmosis of gas from the blood through the walls of the intestinal capillaries. As compared with atmospheric air, though the composition must necessarily be very various, the intestinal gas shows a great excess of carbonic acid and nitrogen, a diminution and sometimes even a total absence of oxygen, the presence of pure hydrogen, and of its carburets and sulphurets. The quantity of this latter gas is less than might be expected from its odor, and, as would be anticipated from the circumstances, the accumulation of gas is much more abundant in the large than in the small intestine.

Schmidt shows that the intermediate circulation of water toward the intestine is far more considerable than its final excretion, and amounts in one day to nearly one fourth of the whole quantity of water in the body.

Water furnished to the intestine.

As the digested mass passes onward, driven by the peristaltic motions through the convolutions of the intestine, it becomes of a more solid consistency, as the absorbents gradually remove its liquid portions. By the time it has reached the cœcum, the same effect which arose in the stomach from salivary digestion is repeated, for the traces of unabsorbed lactic acid cause nutritive digestion to be again feebly resumed, at all events in herbivorous animals, if not in man, whose cœcum is rudimentary, under the form of the appendix vermiformis. From Peyer's glands a secretion has exuded, which perhaps gives to the mass the characteristic odor it is now assuming, if, indeed, these organs are not connected with absorption. The effete remains are finally voided as fæces, which, due allowance being made for the water they contain, amounting to about 75 per cent., may be represented as averaging about 1¼ ounce per day. These excrementitious remains, colored yellow by the coloring material of the bile, are partly derived from the residues of the food which have been unacted upon, and partly from the decay of the system itself. The microscope shows the remains of cell membranes, and the walls of vegetable vascular tissues, starch granules, and chlorophyll, the relics of cartilaginous and fibrous tissues, shreds of muscular fibre, fat-cells. From the digestive tract there have been derived mucus corpuscles, epithelial cells, and the coloring matter of the bile. Perhaps, too, much of the water which gives consistency to the fæces has been derived from the intestinal walls, for in quantity, under certain circumstances, it may exceed the amount that has been used as drink.

Complex changes in the intestinal contents.

Formation of fæces.

In its passage through the intestine, that portion of the bile which has not been absorbed undergoes considerable changes, its conjugated acids degenerating into dyslysin, which may be recognized in the fæces, as is also the case with the modified pigmentary matters; the soluble mineral constituents are, for the most part, absorbed.

Disappearance of the bile.

The reducing agencies in the intestine, and the manner in which substances can find their way into the urinary secretion, is well illustrated by the administration of indigo, which undergoes deoxidation into the condition of suboxide of isatine, and will, notwithstanding the agency of arterial blood, appear in that condition in the urine, to which, upon contact of the air, it imparts a blue tint, becoming more intense under a prolonged exposure, and eventually indigo-blue being deposited. Such a result not only shows how energetic are the reducing agencies in the intestine, but also with what facility very oxidiz-

Incidental reducing action in the intestine.

able material may, under certain conditions, be exposed to arterial blood without oxidation. Yet that this want of action is wholly due to incidental circumstances is shown from the fact that salts of organic acids are much more quickly oxidized in the blood than they are in the open air.

Advantage taken of the decay of one portion to organize another.

It is interesting thus to observe how the death of one part of the body ministers to the life of the rest; for the nitrogenized and active principles of the juices secreted for the accomplishment of digestion are on the descending career, and are truly dying matter. The incipient stage of decay through which they are passing reacts on the food, and prepares it in a temporary manner to replace those parts of the body which are ceasing from activity, and about to be removed.

CHAPTER V.

OF ABSORPTION.

Double Mechanism for Absorption.—The Lacteals and Veins.—Lacteal Absorption.—Description of a Villus.—Analogies in Plants.—Introduction of Fat by the Villi.—The Chyle.—Causes of the Flow of Chyle.—Intermediate Changes on its Passage to the Blood.—Action of Peyer's Bodies.—Lymphatic Absorption.—Nature of Lymph.—Structure of the Lymphatic System.—Comparison of Chyle, Lymph, and Serum.—Function of the Lymphatic System.—Production of Fibrin.—Cutaneous Absorption.—Causes of the Flow of Lymph.—Apparent selecting power of the Absorbents.—Connection of the Lacteals and Lymphatics with the Locomotive and Respiratory Mechanism.

Double mechanism for absorption.

THE food, after digestion, though in the alimentary tract, is exterior to the animal system. Means have therefore to be resorted to for its introduction into the circulation, and its distribution to every part. This is accomplished by a double mechanism, one portion of which is adapted to the digestion which has been going on in the stomach, the other to that which is completed in the intestine. The veins which are profusely spread on the walls of the digestive cavity constitute the former apparatus, the lacteal vessels the latter.

Description of a villus.

The lacteal vessels may be described as delicate tubes, conveying materials absorbed from the intestine into the blood. Their mode of origin may be understood by considering them as projecting with a fine but blunt end upon the inner coat of the intestine. This projection is covered over with smooth muscle cells and a plexus of blood-vessels, a continuation, as it were, of those of the mucous coat of the intestine itself; they are held together by connective tissue, and over that is cast a covering of cylindric epithelium. This construction con-

stitutes what is called a villus, the shape of which is conical, or perhaps cylindrical. The villus may then be regarded as a process of mucous membrane.

Fig. 23.

Section of wall of ileum magnified 50 diameters.

Structure of the intestinal wall.

Fig. 23 is a section of the wall of the ileum, *a* being the villi; *b*, glands of Lieberkuhn; *c*, muscular layer of mucous membrane; *d*, follicles of a Peyer's patch; *e*, remainder of submucous tissue beneath them; *f*, circular muscles; *g h*, longitudinal muscles. (Kolliker.)

Fig. 24 represents the distribution of blood-vessels to the villi of the intestine of the mon-

Fig. 24.

Distribution of arteries and veins on villi of monkey.

key. The figure was drawn by the camera lucida, *a a* being the arteries, *b b* the veins.

Forms of villi.

The form of the villi differs in different regions of the intestine. In the duodenum they are less elevated, laminated, and broader, *Fig.* 25. In the jejunum, more projecting or cylindroid,

Fig. 25.

Distribution of blood-vessels on the villi of the duodenum.

Fig. 26.

Distribution of blood-vessels on the villi of the jejunum.

Fig. 26. In all cases, however, they are abundantly supplied with blood-

vessels. Their epithelial covering of cylindroid cells is shown in the sectional diagram, *Fig.* 27, *a a*; at *b b* is the origin of the lacteal arising obscurely.

Fig. 27.

Conical villi in section, with cylindroid epithelium.

So amply are the villi supplied with blood-vessels, that if, after injection with coloring material, their cylindric epithelium be removed, they seem to be tinged all over. Each cell of the epithelium appears to be filled with granular matter, and to have a well-marked nucleus. Some anatomists assert that that end of these cells nearest the cavity of the intestine is in reality open, and in this manner they account for the ready passage of oil globules into them, and also for the appearance of solid foreign bodies, as Osterlein observed.

Various opinions respecting the epithelial cells.

Though we have described the lacteal as a vessel projecting into the interior of the intestine, it is by some viewed rather as a mere excavation in the villus. The villi impart to the mucous membrane an aspect sometimes likened to the pile of velvet. On an average, their number upon a square inch is about 10,000. The entire number of these organisms must, therefore, amount to many millions. At one time it was supposed that the lacteals open directly into the intestine—an opinion which is now universally abandoned. The action of each villus is doubtless more complicated than is generally represented, for the organic fibre cells it contains give to it the power of executing rhythmic motions.

Origin of the lacteal.

When the operation of the lacteal vessels as absorbents was first detected, it was believed that all nutriment is introduced by their means. But there are many animals wholly destitute of this system of tubes, for instance, the invertebrates. Even in many fishes the villi are absent. In such cases absorption must necessarily be conducted by the veins. Moreover, though there are no lacteals on the walls of the stomach, nor, indeed, on that part of the intestinal tube which is higher than the place of introduction of the biliary and pancreatic ducts, there are many substances freely absorbed from the gastric cavity when its pyloric orifice is tied. It has already been mentioned that the stomach absorbs water with remarkable rapidity. The doctrine that the lacteals are the exclusive organs of absorption must, therefore, be abandoned, for it is plain that the venous system participates in this duty.

The lacteals not the exclusive organs of absorption.

The function of absorption has therefore to be examined from two points of view. As there are two digestions, one producing a perfect so-

lution, and the other an emulsioned, but not dissolved state of the food, so there are two absorbent systems, the lacteals and the veins. The lacteals introduce such substances as are not absolutely dissolved, particularly the oils and fats. The veins appear to take up those substances only which are completely dissolved in water.

Conditions of lacteal and of venous absorption.

As in many other cases in physiology, so in this, a correct interpretation of the functions of the animal mechanism may be obtained by examining the corresponding structures and functions in plants. In the more perfect of these, the absorption of watery material from the ground, constituting the ascending sap, is brought about by the agency of collections of soft cells, which are placed at the extremity of each rootlet. They are designated spongioles. By their action the fluid is forced up through the tubes of the sap-wood into the leaves, and there exposed to the conjoint agency of the sun and air. A change is thus accomplished, and, from being crude, it turns into elaborated sap, and now descends through the bark, to be distributed to every part of the plant. Its ascent is caused by the cells of the spongioles, its descent by the chemical changes occurring among the cells which are found in the structure of the leaves.

Absorption in plants, their ascending sap.

These cells—both of the roots and of the leaves—are far from continuing their action for an unlimited period of time. At the most, their existence is transient. Those of the roots are gradually lost by decay, or converted into solid structure, as the elongation of the organs through the ground goes on. Those of the leaves are equally transitory. At periodic intervals, both in deciduous and evergreen plants, the fall of the leaf occurs—a new organism succeeding in another summer to make up for the one which has passed away.

Whatever nutrient material is taken from the soil in the case of plants is introduced by the aid of a cellular structure, and the cells die after accomplishing their duty.

It was once a saying among physiologists that the lacteals are the roots of animals, and in this there is, in reality, a great deal of truth, for between the rootlet of a plant and the lacteal of an animal there is a conspicuous relation, not only in structure, but also in function. As is seen in *Fig.* 27, upon each villus of the intestinal tube there is a layer of cylindric cells, underneath which the lacteal vessel takes its rise, for it does not open by a free orifice on the interior of the intestine, but its flask-shaped, loop-like, or convoluted origin is obscurely seen in the midst of the cells. The aspect which the villi present, from its doubtful nature, has led to the erroneous conclusion that, as soon as active digestion goes forward, cells rapidly develop within the epithelium, and continue to do so as long as the intestine contains

Analogy between the lacteals and plant roots.

digested matter; that they become turgid with chyle, and have a diameter of about the $\frac{1}{1000}$ of an inch; that, as they select material, they throw it into the lacteal tube, either by bursting or deliquescing, and at the same time set free broods of germs from which new cells are developed. So far, therefore, as their duration is concerned, if this be their true history, they are even more transitory than the corresponding cells of plants.

Fat is introduced by the lacteals into the blood.

That the lacteals are connected with respiratory digestion seems to be plainly indicated by the circumstances of their occurrence. None of them are found upon the stomach, nor even on that part of the duodenum which is above the entrance of the hepatic and pancreatic ducts, but below that point they are scattered in profusion all over the small intestine. The digestion of fatty bodies not taking place until the food has gained the duodenum, vessels for the absorption of the emulsions to which that digestion gives rise are not required until after that point is passed. Correctly speaking, however, the lacteals are only lymphatics which are taking up oil presented to them. In view of the use which the oils subserve in the animal economy, the lacteals are in reality an appendix to the respiratory system. There can be no doubt that through their channel oils and fats, under the form of emulsions, are transmitted to the blood. The analysis of the chyle shows that it is always rich in fat, and, indeed, it is supposed by some physiologists that the objects just described as cells, surrounding the origin of the lacteals, are nothing more than oil or fat globules accumulated there and waiting to be taken up, or that the disappearance and exuviation of the so-called cells is an optical deception, due to their walls becoming permeated with oil.

The manner in which oil globules collect round the villus I have remarked as being very strikingly displayed in the case of the gray squirrel after feeding on fatty nuts. As shown in *Fig.* 28, the whole structure looks as if it were distended with oil globules, *a a*, in the midst of which the origin of the lacteal, *b b b*, may be doubtfully and dimly discerned.

Fig. 28.

Half-diagram of villi of the gray squirrel after feeding on nuts.

Evolution and function of the cells of the villi.

Although it can not be admitted that the production and deliquescence of the cells of villi is a demonstrated fact, and that on this the action of the lacteals as absorbent vessels for the most part depends, the rapid evolution and disappearance of these cells is by no means a physiological impossibility. Botanists assert that, in a single night, the Bovista giganteum, a puff-ball, can develop from a mere point to such a size that it must contain fifty thousand millions of cells—a number that seems almost incredible. The

development of cells in the villi of the intestinal tube, in countless crowds, may therefore be within the bounds of possibility.

If this be the case, the cells which thus come rapidly into existence in the villi appropriate those articles of respiratory food which are of imperfect solubility in water. To this class the oils belong. Each cell then, as it dies, yields up its contents to the lacteal tube. In the white fluid, the chyle, which flows along those tubes, are many pale or colorless corpuscles continually coming into existence. These seem to impress a change upon the chyle, and, to give a full opportunity for such action, that fluid is compelled to flow gradually through long and sinuous channels, for the glands in the mesentery may be regarded as convoluted windings, or rather plexuses of tubes, to which that particular form is given for the sake of closeness of package. From the enveloping capsule of fibrous tissue of the glands thin sheets are projected, and so internetted as to divide the whole gland into many alveoli. These are filled with a pulpy material supplied with delicate blood-vessels. The chyle either oozing through this material eventually escapes from the gland by the efferent vessels, or makes the passage in its own thin tube. In reptiles, in which there are no such glands, the lacteals are extended to a very great length.

Structure of the mesenteric glands.

The manner in which the chyle passes through the mesenteric glands is therefore explained differently, according to the view which is taken of the structure of those organs. If they are considered as mere dilatations of the lacteal vessel, from the sides of which partition processes are sent off, the interspaces being filled with granular material, through which delicate blood-vessels pass, the chyle is to be considered as oozing through this granular structure, and crossing directly in contact with it. But if we accept the doctrine that the chyle is conducted through the gland in a plexus arising from the incoming lacteal, the granular material being outside, then the influence of that material, in whatever it may consist, takes effect through the delicate walls of the plexus. The like remarks apply to the lymphatic glands. Physically, however, the condition in both cases is the same; the incoming liquid is simultaneously exposed in the gland to the influence of the granular pulp and to arterial blood.

Mode of action of the mesenteric glands.

The chyle, delivered into the lacteal tube, is propelled by the conjoint action of several different forces. The constant accumulation of liquid at the origin of the vessel produces a pressure which can only be relieved by motion through the tube, and at the mouth, where the lacteal empties into a vein, as sooner or later all do, either directly or through the intervention of the thoracic duct, a suction force is exerted on the contents of the lacteal by the passing current of the venous blood, upon the well-known hydraulic principle of Venturi,

Causes of the flow of the chyle.

that if into a tube, *a b*, *Fig.* 29, through which a current of water is steadily flowing, another tube, *c d*, opens, its more distant end being in communication with a reservoir of water, *e*, through this tube a current will likewise be established, and the reservoir be emptied of its contents. The effect is still greater, as Bernouilli demonstrated, when the main current is flowing toward the wide end of a conical pipe. Moreover, the lacteal tubes are elastic, and furnished with valves, which open to let the fluid pass toward the veins, but close in the opposite way. This valvular mechanism renders available any pressure arising either from the contractility of the vessels themselves, or from those various muscular movements, respiratory or voluntary, which affect the abdominal walls. The manner of introduction of the great lacteal trunk—the thoracic duct—at the angle of junction of the left subclavian and jugular veins, is also very felicitous, for the suction force of those large vessels is there conjoined, and the effect is at a maximum. The control of the blood motion on the chyle motion is obvious from this, that as soon as the circulation stops the chyle stops, and this not so much from the engorgement of the venous trunks, which renders it difficult for the chyle to make its way into them, as from the cessation of that tractile force, which solicits the chyle to move into the blood.

Fig. 29.

Principle of Venturi.

Mechanism for transferring chyle from the villus to the blood-vessels.

Fig. 30.

The thoracic duct.

Fig. 30 represents the position and course of the thoracic duct, and its manner of introduction of the chyle into the blood circulation. (Wilson.)

1, Arch of aorta; 2, thoracic aorta; 3, abdominal aorta; 4, arteria innominata, dividing into right carotid and right subclavian arteries; 5, left carotid; 6, left subclavian; 7, superior cava, formed by the junction of, 8, the two venæ innominatæ, and these by the junction, 9, of the internal jugular and subclavian on each side; 10, the greater vena azygos; 11, the termination of the lesser in the greater vena azygos; 12, recep-

taculum chyli, several lymphatic trunks opening into it; 13, the thoracic duct, dividing opposite the middle of the dorsal vertebræ into two branches, which soon reunite; the course of the duct behind the arch of the aorta and left subclavian artery is shown by a dotted line; 14, the duct, making its turn at the root of the neck, and receiving several lymphatic trunks previously to terminating in the posterior aspect of the junction of the internal jugular and subclavian vein; 15, the termination of the trunk of the ductus lymphaticus dexter.

Manner of the introduction of fat.

As to the manner in which digested fat finds its way into the lacteals, it seems to be as follows: In the interior of the epithelial cells oil-drops are detected, while on the outer part the surface presents a pearly aspect, from other portions of oil waiting to enter. By degrees, all the cells upon the exterior of the villus exhibit the same appearance, the particles gradually finding their way through the parenchyma of the villus, and so entering the lacteal tube. If, with some anatomists, we regard the lacteal at its origin as not being a true vessel, but only an excavation in that parenchyma, much of the obscurity which surrounds the explanation of the manner of the entry of oleaginous material into the lacteal is removed. If, moreover, with other anatomists, we represent the intestinal end of the cylindric cells to be wanting, and the cells themselves to be truly cup-shaped forms, filled with a peculiar secretion, through which fat particles and even solid substances may pierce their way, this likewise would remove much of the difficulty. But, after all, even if the general opinion of the structure of a villus is adopted, that the lacteal commences with a blind pouch or blunt tube surrounded by a network of blood-vessels, and over this an epithelium cast, there being no mouths, or pores, or apertures of discoverable size leading into the lacteal through its own wall and enveloping structures, we should also remember the extreme minuteness of the oily particles suspended in the chyle, and still more particularly that even this size, small as it is, is deceptive; for, in passing through interstices too minute to be seen even by optical aid, the oil particles may be pressed out into long, thread-like forms, which, as soon as they escape into the free cavity of the lacteal, assume the spheroidal appearance by reason of their own cohesion, just as a blood-cell can pass through a vessel of a diameter far less than its own by lengthening itself out into a linear shape, and reassuming its original figure as soon as it escapes from confinement and pressure. Though, therefore, the lacteals commence upon the intestinal walls as closed tubes, this, in reality, offers no obstacle to their absorbing power when their molecular porosity is considered.

Perhaps this infiltration or intrusion of oily material is, to a considerable extent, aided by the presence of the bile, or, rather, its oily constituent. It is capable of easy demonstration that oil will rise much

higher in a capillary glass tube, the inside of which has been coated over with bile, than in the one which has not been so prepared.

The liquid which has been gathered into the lacteals from the intestine pursues its course to the veins, and ultimately enters them. The special changes which are impressed on it during this passage will now be explained.

Constitution and changes in the chyle.

The constitution of the chyle varies with the physiological conditions of the system. After a period of fasting it is colorless, and presents the general aspect of lymph, hereafter to be described, but during digestion it is a whitish milky fluid, whence its name. This milkiness depends on the suspension of minute fat or oil globules in it. Their diameter is commonly stated at the $\frac{1}{36000}$ of an inch. Of course, the composition of the chyle varies in different animals, and even in the same animal under different diets.

Composition of Chyle.

	Horse.	Ass.	Cat.	Man.
Water	935.00	902.37	905.70	904.80
Fat	15.00	36.01	32.70	9.20
Fibrin	.75	3.70	1.30	70.80
Albumen	35.00	35.16	48.90	
Extractive	6.25	15.65		10.80
Salts	8.00	7.11	11.40	4.40
	1000.00	1000.00	1000.00	1000.00

With so many causes of variation, such a table as the preceding is only valuable as giving a general idea of the nature of the chyle. We learn from it that the predominating solid constituents are fat and albumen. The percentage amount of the first of these in the sample of human chyle is very low, a fact due to the circumstance that the subject from which it was obtained—an executed criminal—had eaten but little for some time before his death. In like manner, the chyle of horses which have been kept without food has been observed to exhibit a diminution of its fat to such an extent as to be less than one tenth of the normal amount. It is to be remarked that the saline ingredients of the chyle closely represent those of the blood, both in constitution and amount.

Constitution of chyle at various points of its course.

The composition of the chyle varies at different points on its passage to the veins, there being a gradual diminution of the albumen and an increase of the fibrin. After the passage through the mesenteric glands it becomes capable of coagulation, and will separate into a serum and a clot. Examined near the villi, it may be regarded as an albuminous liquid, in which are suspended globules of fat of various sizes, down to the degree of minuteness just specified. The nature of these globules is determined by the action of sulphuric ether, which readily dissolves them. After passing through the

mesenteric glands, the percentage amount of albumen declines, and the fat globules diminish in number. Simultaneously the special cells, to which the name of chyle corpuscles is given, make their appearance, and the liquid is now capable of coagulating, owing to the production of fibrin. These characters become more strikingly developed as the chyle advances in the thoracic duct. The chyle corpuscles are eventually developed into red blood-cells.

It is affected by transudation from the blood.

It should be borne in mind, in all discussions respecting the composition of chyle in different parts of its course, that it must receive transuded matters from the blood, and that this must more particularly occur on its passage through the mesenteric glands. Owing to this, it is quite probable that, even though there should be an actual consumption of albumen in accomplishing the metamorphoses which are taking place, the apparent percentage amount of that ingredient may increase by transudation from the blood. It appears to me quite probable that the albuminous material in the lacteal, at its very origin in the villus, has been derived to quite as great an extent by transudation from the plexus of blood-vessels as by absorption from the digested food.

Saponification of the fat.

Whatever may be the special manner by which the fats pass from the intestine into the lacteals, they have scarcely gained those vessels before they undergo a change. The quantity of free fat diminishes, and that of saponified fat increases; this is probably accomplished by soda obtained from the blood.

Difference between blood-fibrin and chyle-fibrin.

As to the fibrin, it can scarcely be supposed that the imperfectly coagulable variety which the chyle contains should have been derived by transudation through the vessels of the strongly contractile kind contained in the blood; and, in view of all the circumstances of the case, it would appear that the explanation we shall offer of its direct origination from the chyle albumen by oxidation is correct.

Fig. 31.

Chyle corpuscles with blood-cells, magnified 250 diameters.

Nature of chyle corpuscles and action of reagents on them.

The chyle corpuscles are readily distinguished from the blood-cells, not only by their white appearance, but also by their form. They are spheroidal, and either homogeneous or granular. Those of the frog are seen in *Fig.* 31, at *a a*, sparsely scattered among the elliptical blood-cells. The photograph from which the engraving is taken exhibits nearly the average proportion of these bodies in that animal.

By the action of water, the nucleus of the chyle-cell becomes more distinct, its increased granular aspect making it more visible, as in *Fig.* 32.

Fig. 32.

Chyle corpuscles with water, magnified 500 diameters.

Fig. 33.

Chyle corpuscles with acetic acid, magnified 500 diameters.

By acetic acid the nucleus is greatly contracted, as in *Fig.* 33, and sometimes even escapes from the cell.

In embryonic life, the first appearance of chyle corpuscles commonly coincides with a change in the arrangement of the respiratory mechanism, as the closing of the branchial fissures, indicating a connection between their production and the activity of interstitial oxidation.

It has been previously stated that the bodies known as Peyer's glands are to be regarded as belonging to the absorbent rather than the digestive apparatus. In structure they are analogous to the lymphatic and lacteal glands, consisting of a capsule containing granular material, in which loops of capillary blood-vessels are laid. From these proceed many lacteal vessels, as may be very plainly observed during digestion. Their functions would therefore seem to be the submitting of the chyle to the simultaneous influence of the blood brought by the arterial capillaries, and the pulpy material or granular plasma they contain. They are, in reality, dilatations of the absorbent vessels, accomplishing in a small space a result which would otherwise demand a very long lacteal tube, and probably not impressing any other change on the chyle than that which would have occurred in such a tube, if of sufficient length.

Peyer's bodies an appendix to the lacteal system.

It is not possible clearly to understand the functions of the lacteals without a description of the structure and functions of the lymphatics, for these vessels conspire in their action.

Structure and functions of the lymphatics.

Anatomical, chemical, and physiological considerations lead us to conclude that the formation of the LYMPHATIC SYSTEM is closely allied to that of the LACTEAL. The two classes of vessels make their appearance together in fishes; the lymphatics originate in a network of delicate tubes, but are disseminated through all the soft tissues except the nervous, and are found especially in the skin. The fine ini-

tial tubes gradually coalesce, producing those that are of a larger diameter, and these pass through glands, which might indeed be regarded as mere plexuses, and eventually empty into the veins.

Properties of lymph.

A few minutes after it has been drawn, the lymph coagulates into a colorless clot, and then exhibits contraction. Compared with blood in like circumstances, the clot of lymph is small in relation to the serous portion. In other respects there is a general resemblance between lymph and blood free from its red cells, the fibrin and the albumen being apparently the same in the two cases. The saline constituents are not only the same, but bear the same ratio to one another in the two fluids. Their absolute percentage amount differs, because the lymph contains a larger proportion of water than the blood.

The lymph arising, as we shall find, by transudation from the capillaries, must obviously vary in different parts, those parts taking from the blood the materials they require for their nutrition, and yielding to it the products that have arisen during their waste. Whatever in this manner changes the composition of the blood, must also occasion a change in the transuded liquid. Thus Schmidt has shown that protein bodies transude through the capillaries of the pleura most copiously; through those of the peritoneum not to half that amount; through those of the brain and those of the subcutaneous areolar tissue to a less and less extent. Not only must the material thus oozing from the capillaries vary in different regions, because of variations in the mechanical constitution of those vessels, but it must also change even in the same locality, through temporary accidents, such as changes in the velocity with which the blood is flowing. An attempt has been made to show that the transudation will be richest in albumen as the blood current in the capillaries is slower.

Composition of lymph.

When the contents of the lymphatic vessels are submitted to analysis, and compared with the chyle, a striking difference is apparent. The chyle contains, as has been already stated, large but variable proportions of fat or oil in an extremely subdivided state, from which the lymph is free. The leading solid constituent of the lymph is albumen, and this indicates the use of the system.

Composition of Lymph.

	Horse.	Ass.	Man.
Water	950.00	965.36	961.00
Fat	.09		
Fibrin	39.11	1.20	2.50
Albumen		12.00	27.50
Extractive..............	4.88	15.59	6.90
Salts	5.92	5.85	2.10
	1000.00	1000.00	1000.00

Fasting chyle is lymph.

The functional connection between the lacteals and lymph vessels is very well illustrated by the following analysis, which exhibits the composition of chyle obtained from the thoracic

duct of a man who died from softening of the brain, and who took nothing but a little water for 30 hours preceding his death. (L'Heritier.)

Composition of Chyle after Fasting.

Water	924.36
Fat	5.10
Fibrin	3.20
Albumen	60.02
Salts	7.32
	1000.00

Comparison of lymph and chyle.

The constitution of the chyle so nearly approaches that of the lymph, that we are authorized to conclude that, during fasting, the lacteals transmit lymph, and the conclusion gives force to the observation already made, that the albumen of chyle is derived rather from the blood capillaries than from the digested food.

Comparison of the lymph and serum.

On comparing together the salts of the serum of the blood and those of the lymph as obtained from the horse, they appear to coincide.

Salts of Serum and Lymph.

	Serum.	Lymph.
Alkaline chlorides	4.055	4.123
Alkaline carbonates	1.130	1.135
Alkaline sulphates	.311	.233
Alkaline phosphates	.115	.120
	5.611	5.611

Office of the lymphatic system.

From the indications presented in these tables, there can be no doubt that the office of the lymphatics is to collect the albuminous matters which have every where transuded from the blood-vessels, or been set free by changes going on in the soft parts. Such matters, though they may be regarded as being in one sense dead, are yet as applicable for the further support of the mechanism as are the albumenoid bodies introduced as food, and said to be taken up by the lacteals. The last table shows that the lymph is really nothing but a diluted serum. A mechanism is therefore resorted to to turn this collected albumen into fibrin, and thus arises a lymphatic gland—a contrivance which tends greatly to compactness. This structure is the counterpart of the mesenteric or lacteal gland. It may be described as originating from the coalescence of two or three lymph vessels, which, casting off their external coat as they enter the gland, anastomose with one another in various ways, so as to form plexuses and convolutions. The capsule of the gland, strengthened by the coat it has received from the entering vessels, sends forth partition-like processes, which dip down into the grayish pulpy material filling the interstices. On their emergence from the gland the vessels recover from it their external coat, and, during their passage through it in their naked state, blood-vessels are distributed upon them. The ob-

Structure of lymphatic glands.

ject of the arrangement seems to be to submit the liquid contained in the lymph vessel to the action of the pulpy material of the gland and arterial blood under the most favorable circumstances, the thinness of the wall and the convolved plexus being well adapted to that end.

Fig. 34.

Lymphatics of the large intestine.

Fig. 34 illustrates the lymphatics of the large intestine, the adjoining parts being cut or displaced to display them; *a*, *a*, ascending and transverse colon drawn aside; *b*, *b*, descending colon and its sigmoid flexure drawn aside; *c*, cœcum; *d*, stomach; *e*, duodenum; *f*, jejunum cut; *g*, *h*, *i*, lymphatics and their glands. In such an arrangement as this, the lymph is far more perfectly exposed to the influences to which it has to be submitted than it could possibly be in straight tubes. In reptiles, however, this package is not resorted to, and the tubes, being spread out, give the false appearance of a greater development to this system than in the higher tribes. In the mammalia, according to Professor Goodsir, wherever the lymph tube enters the gland, it changes its internal constitution, losing the scale-like covering that its inner coat presented, and offering a numerous development of nucleated cells, many of which adhere to the membrane beneath, but many float away and drift with the lymph in its course. There is a constant reproduction of these organisms, and they seem to be connected with a change in the albumenoid constituent of the lymph, turning it into fibrin. And thus, if examination is made of the lymph before it enters a gland and after it has passed through, in the former instance it seems to differ but little from the liquor sanguinis, or serous portion of the blood, as has been already shown, but in the latter fibrin begins to abound.

Production of fibrin in lymph glands.

Professor Goodsir's view is represented in the diagram, *Fig.* 35, showing the scale-like epithelial cells of the lymphatic tube changing into the nucleated cells of the gland.

Fig. 35.

Diagram of a lymph gland.

Fig. 36.

Evolution of cells in lymph gland.

Fig. 36 illustrates the generation of broods of cells, some being attached and some free.

Some chemists, adopting the views of Liebig respecting the essential difference between blood fibrin and muscle fibrin, look upon the former substance, not as a histogenetic, but as an effete body, a conclusion which, of course, would have an important bearing upon the interpretation of the function of the glands as here given, as likewise upon that in the corresponding case of the chyle. The weight of physiological evidence is, however, so strongly against this doctrine, that we are constrained to retain the old one, and therefore to regard the production of fibrin as one of the important duties of the lymphatic system.

Fibrin not an effete body.

The absorbent vessels, whether lacteals or lymphatics, have therefore a common duty of changing albuminose or albumen into fibrin, and thereby of compensating for the constant waste of that substance which is going on in the wear and tear of the muscular system. The constitution of the urine proves that the amount of muscular fibrin destroyed in short periods of time is very great. We can not estimate the hourly consumption at less than 62 grains. Such a waste must demand an equivalent compensation, if the animal mechanism is to be kept up unimpaired, and every care is therefore taken to omit no means which may incidentally offer for husbanding the necessary materials. The action of the lymphatics illustrates this principle significantly. Passing through all the soft solids where exudation of albumen from the blood-vessels can take place, they collect the materials that would otherwise go to waste, and add thereto many of the products arising from the disintegration and decay of the soft parts themselves. Receiving all these, they transmit them through their windings in the glands, and thus submit them to the action of the innumerable cells which are there coming into existence. As in the egg of a bird, in which, as the albumen slowly disappears, the muscular tissues of the young chicken arise, so here the serous portion disappears, and fibrin comes in its stead, and this is hurried forward to the torrent of the circulation, and thrown into the blood-vessels, to be by them distributed to all parts of the mechanism, wherever the muscular tissues are in want of repair.

Its mode of production and quantity.

But, besides this function of the elaboration of fibrin, there can be no question that the lymphatics have other incidental uses. Many facts are known which prove that those of the skin exert a powerful agency in absorbing liquid material. Thus a person who has abstained from water will, after he has immersed his body in a bath, not only find his weight increased, but the sensation of thirst abated. Instances of the kind are on record where sailors, in open boats without fresh water, have assuaged the torments of thirst by immersing their bodies in the sea. Nay, it is even asserted that in certain conditions water may thus be obtained from the atmospheric air, and in

Cutaneous lymphatic absorption.

all such cases every thing points out that the lymphatic vessels are the avenues through which the liquid is introduced.

In what manner does the lymph move? In reptiles there are found what are termed lymphatic hearts, which are merely dilated portions of a tube exhibiting pulsation. Of these, in the frog, two pairs may be discovered, one behind the hip-joint, and situated so superficially that the motions can be plainly seen; the other is at the anterior part of the chest. The pulsating movements of these organs, of course, impel the liquid acted on in the direction determined by the valves with which the vessels are so profusely supplied, that is, to the general circulation, and the lymph finally enters the blood-vessels.

Cause of the flow of lymph.

But in the higher tribes these organs of impulsion are absent, and the circulation through the vessels is determined by the agencies mentioned in the case of the lacteals. 1st. By the constant accumulation of liquid at the origin of the tube; 2d. By every muscular movement, either voluntary or involuntary, which produces a compression of the tube, the valves all opening one way, and therefore causing the included liquid to pass in one direction only; 3d. By the exhaustive action at the mouth of the lymphatic, arising from the passage of the blood. It ought, perhaps, to be prominently pointed out, as belonging to the second of these causes, that the pulsation of the arterial trunks adjacent to any lymphatic brings the power of the heart itself into operation in an indirect way.

Though the absorbents will receive many different bodies and transmit them to the veins, the action does not take place in an indiscriminate manner. Certain substances, such as the fats and albumen, find a ready entrance, but admission to others is wholly denied. Thus it has long been known that if coloring matter be introduced into the intestine, it by no means follows that the chyle will be tinged. If an animal be compelled to take litmus-water, the chyle will still be found colorless or white. On such facts was founded the old doctrine that these organs possess a low species of intelligence, distinguishing among different substances, permitting some to enter them, and refusing a passage to others. Many years ago I showed that these fanciful cases are capable of a simple physical explanation. Thus I found that if blue litmus water was tied up in a bladder, or a piece of peritoneum, and sunk in a vessel of alcohol, though the water would rapidly infiltrate into the alcohol, the coloring matter would be stopped just as it is in the intestine. But, in reality, there is no need of such experiments to satisfy us of the fictitious nature of this selecting power. If we fill a lamp half full of oil and half of water, and immerse in it a wick long enough to dip into both, if the wick be previously soaked in oil, it will withdraw from the lamp oil alone, and continue to do so until the

Apparent selecting power of absorbents.

lamp ceases to burn; but if it be first soaked in water, it will wholly refuse to take the oil, and remove the water alone, until all is escaped by evaporation. But did ever any one impute to the wick of a lamp a power of intellectuality, no matter how obscure, or suppose that there is any thing mysterious in such a selecting operation? A perpetual reference of the most common facts to mysterious agencies has been the great barrier to the advance of medical science. This system was introduced by the alchemists and quacks of the Middle Ages, and even now it will take many books and many years before physiology can be rescued from such visionary theories.

Connection of lacteals and lymphatics with motion and respiration.

From the point to which our descriptions have brought us, we have to regard this part of the absorbent mechanism as connected with two great animal functions, motion and respiration. Both its divisions, the lymphatics and the lacteals, in preparing fibrin from albumen, make provision for the repair of the muscular tissues, and are therefore to be regarded as a portion of the motive apparatus. But the lacteals are charged with a farther duty, and in a double manner are connected with the respiratory mechanism, for they not only introduce fats into the system, but give origin to the cells of the blood, which are the carriers of oxygen.

We may therefore close this chapter with a few remarks, 1st. On the connection of the absorbent system with the provisions for motion; 2d. On its connection with the respiratory function, as more particularly displayed by the preparation of blood-cells.

1st. The connection of the absorbent system with the provisions for motion is through its function of preparing fibrin from albumen.

Fabrication of fibrin.

From the membrane which lines the plexus of tubes of which the mesenteric and lymphatic glands are composed, crowds of nucleated cells are continually arising. As to the function of these cells, there can be little doubt that it is in part to effect the translation of a portion of albumen, which has been introduced along with the oil globules, into fibrin, and accordingly we find that the chyle, analyzed at different parts of its course, yields different products. As has been stated already, intercepted before its passage through these glands, very little fibrin is found, but collected from points beyond, the quantity of fibrin steadily increases and that of albumen declines. The plexus of tubes has therefore for its object to expose its contents to the influence of the cells.

Now what are the chemical conditions under which the transmutation of albumen into fibrin takes place? The problem is most clearly presented in the case of the incubation of a bird's egg. The white of the egg, consisting chiefly of albumen, gradually loses that form, and passes into the state of fibrin as the development of the muscular tissues of the

young chicken is effected; but the change can not take place except oxygen be received through the shell; and, indeed, in all cases in which albumen passes into fibrin, it does so only in the presence of oxygen.

But in the case of the absorbent glands, from what source does the requisite oxygen come? These glands have just been described as plexuses of the absorbent tubes, among the ramifications of which arteries and veins are abundantly distributed, the blood not getting access to the interior of the absorbent, but running in its own vessels, as it were, side by side, and branching on the naked walls of the plexus; and, just as in the placental circulation the arterial blood of the mother vivifies or furnishes oxygen to the fœtal blood, so in this instance the arterial blood enables the cells to discharge their duty of converting the albumen into fibrin, which passes onward to the general circulation for the renovation of the muscular tissues.

Manner in which oxygen is furnished for the making of fibrin.

Since the hourly consumption of fibrin may be taken at 62 grains, the quantity produced by the action of these cells must be the same. We may therefore affirm that the fibrin-producing mechanism yields about one grain in each minute of time.

2d. Contemporaneously with the elaboration of fibrin is the development of the proper chyle corpuscles. Through the evolution of these and the absorption of fat, the chyle vessels present a connection with the respiratory apparatus.

Formation of blood-cells.

If any weight is to be given to the views of Ascherson, the occurrence of fat globules in the chyle is essential to these cellular productions. He found that when globules of oil are placed in a solution of albumen, they become coated over with a film of that substance in a coagulated state, and hence was led to infer that this is the starting-point of cell production generally.

The chyle corpuscles are the embryos of the true red blood-cells, the latter being derived from them by gradual development. As will appear more in detail when we come to the description of the blood, in vertebrated animals there are two distinct classes of red blood-cells, which appertain to distinct periods of life. The first, which are found in man previously to the time of formation of the chyle and lymph, are nucleated, and have the power of reproduction by fissuring of the nucleus.

Two successive forms of blood-cells in man.

But a distinct set gradually replaces the preceding. These cells have no nucleus; they are flattened, bi-concave, and in man circular. They possess no power of reproduction either by fissuring or otherwise. Their origin is from the chyle corpuscle, the granular interior of which clears up, and is succeeded by a deep red tint. The transition from the first to the second of these forms takes place at an early period, and may be

regarded as complete in the human embryo of two months old. After that time blood-cells are generated upon the second plan, from the chyle corpuscles alone.

It is a significant circumstance that this transition from the reproductive to the non-reproductive blood-cell is coincident usually with the disappearance of the external branchiæ, or the closing of the branchial fissures. There can be no question that the destined function of the perfect blood-cell is the introduction of oxygen to the system. In their origin and in their object they are therefore in relation with the respiratory mechanism.

CHAPTER VI.

ABSORPTION BY THE BLOOD-VESSELS.

Proof of Absorption by the Blood Capillaries.—Occurs as a physical Necessity.—Nature of Capillary Attraction.—Its Phenomena in the Rise and Depression of Liquids.—Conditions for producing a Flow in a Capillary Tube.—Passage of Liquids through minute Pores.—General Propositions respecting Capillary Attraction.—Endosmosis and Exosmosis.—They depend on Capillary Attraction.—Force against which these Movements may take place.—Illustrations of selecting Power.—General View of the entire Function of Absorption, lacteal and venous.

Substances are absorbed by the blood capillaries.

THAT the blood-vessels of the stomach and intestinal tube participate in the function of absorption is demonstrated by many different facts. Medicaments placed in the stomach after its pyloric orifice has been tied will produce their specific effect almost as rapidly as under natural circumstances; and, since there are no proper lacteals upon that organ, and its lymphatics seem to be inadequate, the absorption of these agents can have taken place through the blood-vessels only.

This conclusion is substantiated by an examination of the blood of the gastric and mesenteric veins. It varies with the stage of digestion and the nature of the food. At first there is a general lowering of the percentage amount of the solid ingredients, this being evidently the result of the absorption of water. At a more advanced period, the relative proportion of albumen, or rather of albuminose, rises, and along with it the extractive, gelatine, and sugar increase. As with the chyle in the lacteals, so with the blood in the mesenteric veins, coagulation takes place imperfectly, or perhaps not at all. It is stated that the mesenteric blood of a fasting animal does not differ from the ordinary venous blood.

The position of the blood-vessels, both on the mucous surface of the stomach and particularly on the villi of the intestine, is favorable to the

discharge of this function. The term venous absorption, employed to express it, is perhaps somewhat incorrect, since there is no reason that a venous capillary should have any advantage over an arterial one in this respect. The rapidity with which substances in a state of solution are taken up from these cavities has been well demonstrated by such instances as those of the detection of the ferrocyanide of potassium in the urine within 2½ minutes of its having been deposited in the stomach, or by the death of dogs in a similar short period after strong alcohol had been administered to them, their blood being found to be charged with that combustible substance.

Among substances thus finding their way into the circulation by direct vascular absorption may be enumerated such soluble salts as have little affinity for the tissues, mineral and organic acids, alcohol, ether, volatile oils, vegetable alkaloids, and coloring matters, as those of rhubarb, madder, gamboge.

Absorption by the blood-vessels occurs as a physical necessity.

In fact, if there were not these physiological considerations, we should have to admit absorption by the blood-vessels as a matter of physical necessity; for, under the circumstances of their situation, they must take up soluble matters presented to them. Through the pores of their delicate structure substances in the liquid state will pass to mingle with the blood.

Though we have treated of respiratory or lacteal absorption as specifically distinct from absorption by the blood-vessels, the circumstances here alluded to evidently point out that the resulting action of the villi of the intestines is of a mixed kind; for, though the epithelial cells and the commencing pouch of the lacteal may exert a definite influence, the network of blood-vessels which lies immediately beneath the epithelium must be engaged in precisely the same manner as the network of blood-vessels between the gastric follicles. The permeation of the walls of these tubes by substances in a state of solution is dependent, as we are now to see, upon a purely physical principle, which is just as applicable in the one case as it is in the other. The leading solid ingredients of the chyle being fat and albumen, the former is perhaps introduced by the proper lacteal structure, and the latter, taken up by the vascular network, exudes in part again from it into the lacteal arrangement.

In the case of absorption, as in that of respiration, hereafter to be described, there is a physical principle in operation which it is necessary to understand. I shall proceed to explain it on this occasion as far as is needful for the present purpose, and complete the description in the chapter on the function of respiration. The peculiar views here set forth, so far as they differ from those ordinarily expressed, I believe to be warranted by my own experiments elsewhere published.

The absorbent action of the blood-vessels depends on the force known

Capillary attraction.

among physical writers as CAPILLARY ATTRACTION. Its nature may be illustrated as follows:

If a piece of glass be laid on the surface of quicksilver, it is so powerfully attracted thereto as to require the exertion of considerable force to lift it off. Natural philosophers generally regard this as a force sui generis, and speak of it under the title of capillary attraction. I believe it is nothing but an ordinary electrical phenomenon, since, if the glass be examined, it will be found to be in a positively electrified state, and the quicksilver negative, and under the general law of electricity, known as that of Dufay, attraction must be the result.

If the glass be laid upon the surface of water, there is an attraction as before. On lifting it, however, there is no electrical manifestation. The reason of this is plain. On examining this glass, it will be found that no true separation of it from the water has taken place. A film of water is still attached to it, or, in other words, it is *wetted*.

Fig. 37.

Depression of a non-wetting liquid.

Elevation and depression of liquids in capillary tubes.

If a slender glass tube, *b*, *Fig.* 37, be dipped into a liquid, *a*, *a*, which can not wet it, as, for example, quicksilver, the liquid is depressed as at *c*, and does not rise to its proper hydrostatic level, or, perhaps, altogether refuses to enter the tube.

Fig. 38.

Elevation of a wetting liquid.

If a slender glass tube, *b*, *Fig.* 38, be dipped into a liquid, *a*, *a*, which can wet it, as, for example, water, the liquid at once rises in the tube, as at *c*, to a height which is greater in proportion as the diameter of the tube is less. It is this phenomenon which has given the designation *capillary attraction*, because it is best seen in tubes as fine as a hair (capillus).

Now if there be a tube of such a diameter that it could thus lift water ten inches, and it be broken off so as to be only six inches long, we might inquire whether the water would overflow from its top, or simply remain suspended.

Mathematical considerations as well as direct experiments prove that, in such a case, there would be no overflow. A capillary tube under these circumstances simply lifts the water, but can not produce a continuous current.

Conditions for producing a flow.

But if a removal of the water at the top of the tube takes place in any manner, as, for instance, by evaporation, or by being dissolved away, then a continuous current is produced. This fact explains the phenomena of endosmosis, presently to be described.

As illustrative of the production of a continuous flow, we may cite the case of a spirit-lamp, the wick of which may be regarded as a bundle of capillary tubes. If the cover of the lamp be taken off, all the spirit will pass up the wick and escape by evaporation. Or in an oil-lamp, the wick of which becomes readily saturated with the liquid, but never exhibits any overflow, on the lamp being kindled, the oil is burned off, and a current is at once established.

I have shown that water will pass through a crevice, the width of which is less than one half of the millionth of an inch. Pores or crevices of such a dimension are invisible even with a microscope.

Liquids pass through very minute crevices or pores.

The evidence in proof of this is very readily obtained experimentally.

Fig. 39.

Passage of water through a crevice.

If we take a convex lens, *a*, *a*, of long radius, and place it upon a glass plane, *b*, *b*, there will be seen at the point of contact, *c*, on looking down upon the arrangement, a black spot surrounded by a series of variously colored concentric circles, the appearance being well known among optical writers under the name of Newton's colored rings. At the point of apparent contact, *c*, the lens and the plane are, as Newton has shown, a distance apart of about the one half of the millionth of an inch, and from this central point, proceeding outwardly, the distance between the glasses, of course, increases. If any where at the outer portion a drop of water be introduced, it extends itself instantly across all the colored rings, reaching even across the central black spot.

The three following general propositions present those phenomena of capillary attraction which are most interesting in a physiological point of view.

General propositions respecting capillary attraction.

1st. If the force of attraction of the particles of a solid for those of a liquid be not equal to *half* the cohesive force of the latter for each other, the liquid will refuse to pass through a pore of that solid substance, and, in a capillary tube consisting of it, will be depressed below its hydrostatic level.

2d. If the force of attraction of the particles of a solid for those of a liquid exceeds *half* the cohesive force of the latter for each other, but is not equal to the whole force, the liquid will pass through a pore of that solid substance, and, in a capillary tube of it, will rise above its hydrostatic level.

3d. If the force of attraction of the particles of a solid for those of a liquid exceeds the whole cohesive force of the latter, chemical union between them ensues.

It would not be consistent with the plan of this work to offer a demonstration of these propositions; nevertheless, they are capable of rigor-

ous mathematical and physical proof. The views I am here presenting enable us to include the pressures between solids and liquids, the rise or depression of liquids in capillary tubes, and the phenomena of chemical affinity in the same general expression. And such a co-ordination is the more valuable, since there has been a disposition among physiologists to regard the introduction of material through the pores of organized textures as dependent on some ill-defined or mysterious principle.

Endosmosis and exosmosis.

The phenomena of endosmosis, first brought to general notice in the case of liquid substances by M. Dutrochet, may be explained as follows: If some alcohol be placed in a bladder, the neck of which is tightly tied, and the bladder be sunk in a vessel of water, a percolation ensues, so that the bladder distends to its utmost capacity, and might even be burst. Or, which is a better method of showing the result, if, instead of tying the mouth of the bladder, a glass tube, open at both ends, and a foot or two long, be fastened into it without leakage, as the water introduces itself through the pores of the bladder to mingle with the alcohol, the liquid rises in the glass tube, supposed to be left in a vertical position, and, when it has reached the top of it, overflows. To express this inward passage of the water the term endosmosis was introduced, and since a little of the alcohol simultaneously passes outward to mix with the water, it is said to exhibit exosmosis.

Fig. 40.

Endosmosis.

In *Fig.* 40 is represented the endosmometer of Dutrochet. It consists of a small bladder, *a*, tightly tied to a tube, *d*, which is open at both ends, and bent, as seen in the figure at *c*; the bladder being completely filled with alcohol, and the tube to some such point as *d*, the arrangement is to be placed in a vessel of water, *e e*; almost immediately the level of the liquid will be seen to be rising, the bend of the tube is reached, and one drop after another falls from the open end into the glass, *b*. And this continues until the liquids inside and outside of the bladder are uniformly commingled.

These movements are dependent on capillary attraction.

It is to be regretted that the terms endosmosis and exosmosis have been accepted by physiological writers, for in these results there is nothing more than what we should expect from the known principles of capillary attraction. The pores of a bladder, or of any other such organic texture, are nothing but short capillary tubes into which water readily finds its way, because it can *wet* the substance surrounding the pore. If the bladder be distended with air, and sunk under water, although the water will fill the pores, it

will not exude from them, and accumulate in the interior of the viscus, for, as we have seen, a capillary tube can not establish a continued current or flow. But the case becomes totally different when the bladder is filled with alcohol; for then, as fast as the water presents itself on the inner end of the pore, it is dissolved away by the alcohol, and the necessary condition for a continuous flow is complied with. Meantime, through the pore itself a little alcohol passes in the opposite way by infiltrating through the incoming water, provided that the current be not too strong, and so endosmosis of the water and exosmosis of the alcohol take place, the current of the former greatly preponderating over that of the latter, and an accumulation of liquid in the interior of the bladder ensues.

That in all this there is nothing specially dependent on the organic texture employed is obvious from the fact that the same results arise when any inorganic porous body is used. Vessels of unglazed earthenware, pieces of baked slate or stucco, answer the purpose very well, as will also a glass vessel with a minute fissure or crack in it.

An incorrect representation of the conditions under which endosmosis takes place is often made. It is said to depend on the relative specific gravity of the liquids. Thus it is stated that the lighter liquid always moves toward the denser, more abundantly than the denser to the lighter. The error of this is readily shown by many simple illustrations. Thus water endosmoses equally well to alcohol, which is lighter than it, and to gum water or salt water, which are heavier. The relation of specific gravity has nothing whatever to do with the action.

Force against which these movements may take place.

The force with which a liquid will thus pass through a pore to mingle with another liquid beyond is very great. I have observed these motions occurring against a pressure of many atmospheres. And, indeed, in practice we have no means of measuring its actual intensity; for when a pressure of a certain degree has accumulated, hydraulic leakage takes place backward through the pore, and conceals the true action.

From the preceding statements respecting capillary attraction and endosmosis, we may therefore conclude that, whenever a liquid is in contact with a porous body the substance of which it can wet, it will freely pass into the pores thereof, and, if the necessary conditions for its removal are present, will percolate or transfuse with very great mechanical power; that this will take place through pores that are not only invisible to the eye, but imperceptible by the aid of the microscope; that some liquids pass thus with more readiness, some with less, some not at all—the result in these respects depending on the electro-chemical relations subsisting between them and the solid they are in contact with, and their own force of cohesion; that organic membranes present no peculiarities, their action arising, not because they are organic, but be-

cause they are porous; that the so-called selecting power is purely physical, as are the separations and apparent decompositions to which it gives rise. When a drop of colored water is put upon chalk, the water sinks in, but the color is left on the surface. When weak alcohol is tied up in a bladder, the water will escape through the pores, and the spirit become anhydrous at last.

Fig. 41.

Selecting power of a membrane.

If we take a glass tube, *a*, *a*, *Fig.* 41, over the lower end of which a piece of peritoneum, or other delicate membrane, *b*, *b*, is tightly tied, and half fill it with litmus-water, and then place it in a glass of alcohol, *c*, *c*, the level of the liquids inside and outside being adjusted according to their specific gravity, so that there may be no hydrostatic pressure either one way or the other through the pores of the peritoneum—as soon as the arrangement is completed, if the observer be so placed as to view it by transmitted light, he will see the water descending from the pores of the peritoneum in striæ and streams through the alcohol in a perfectly colorless state. The membrane, therefore, has absorbed and transmitted the water, but has refused to the coloring matter a passage. It is to this particular experiment that allusion was made when speaking of the non-coloration of the chyle when certain coloring material had been mixed with the food. Such illustrations may therefore satisfy us that the selecting power of organic porous textures, like that of inorganic ones, is dependent on simple physical circumstances, and for these reasons I exclude from the mechanism of animal absorption the influence of any vital or other mysterious principle, and adopt the sentiment of the Abbé Hauy, that "those specious causes and imaginary powers, to which, in the Middle Ages, all natural phenomena, even those of an astronomical kind, were referred, but which, through the genius of Newton and Laplace, have been banished from the celestial spaces, have taken their last refuge in the recesses of organic beings, and from these retreats positive philosophy is preparing to expel them."

Summary of the nature of absorption.

In view of all the preceding facts, I therefore regard absorption by the blood-vessels as taking place of necessity, because of the porous structure of those tubes; for, though the pores may be too small to be discerned even by microscopic aid, they are abundantly large enough to permit such a percolation. Whatever material is existing in the chyme in a state of solution in water and also soluble in the blood, passes through the walls of the vessels, and is moved toward the liver, its percolation being greatly facilitated by the onward motion of the blood, in which liquid it is dissolved as fast as it presents

itself. The double condition here specified must be complied with; the material to be introduced must be dissolved in water, and must be soluble in the blood. If the latter condition be wanting, the vessels seem to manifest a selecting power, absorption not taking place, as in the case of litmus, presented above as an illustration—a coloring matter which, though soluble in water, is not soluble in alcohol, and so can not, under those circumstances, pass through a piece of bladder.

While thus there is an introduction of digested material from the stomach and intestine into the blood, the physical principles which are guiding us in our explanation teach us that there must be a percolation of the more watery portions of the blood in the opposite direction—that is, into the digestive cavity. There is every reason to believe that this percolation is to a far greater amount than is generally supposed. Under certain circumstances, it is a matter of ordinary observation that the water discharged from the intestine is more in quantity than that which has been taken as drink.

Course of the absorbed material to the liver; modifications it undergoes.

Turning our attention now to the course which is followed by the liquid which has been introduced from the digestive cavity into the blood-vessels, we must bear in mind that the content of those vessels is composed of two distinct portions, the matter thus recently introduced, and the original venous blood. These together make their way through the portal vein to the liver, a gland of double function, and, as we may say in this respect, of double structure; for, though it has a duct for the disposal of the products which arise from its action on one portion of the material thus brought to it, the venous blood, it is ductless as regards the other portion, which has been received from the digestive cavity. This portion, under the influence of the cell structure of the liver, undergoes profound modification; for instance, liver-sugar makes its appearance, though none existed before. It is not necessary for us to specify these changes particularly here, since we shall have to examine them more in detail in a subsequent chapter; but it may be observed that the anatomical peculiarity of the liver in this branch of its duty is, that it simply impresses a change on the compounds thus brought to it, gives rise to no excretions, and therefore has no channel or duct of escape, unless indeed we say, as we are actually justified in doing, that the hepatic veins themselves are the ducts of the liver in this respect.

Though it does not strictly appertain to the subject of which we are now speaking, absorption, we may, for the sake of completeness, describe, in a superficial manner, what occurs to the other constituent of the portal blood, its proper venous portion. This, brought into the liver, is acted upon by that organ and decomposed into two portions, one of which, constituting the bile, is brought back eventually through the proper bile duct

into the intestine. The other is carried into the blood circulation. I believe that this separation is of a purely physical kind, and is accomplished by mere filtration, the elements of the bile all pre-existing in the blood. However that may be, the separation in a chemical sense is very distinct, for the nitrogenized ingredients are saved to the system, and carried into the general circulation through the hepatic veins; but the biliary material brought back into the intestine is a hydrocarbon tinctured with a little coloring matter, which, being on a rapid career of retrograde metamorphosis, is prone to act as a ferment, and therefore unfit to remain in the system; accordingly, it is removed with the excrement. The other portion, the hydrocarbon, which has been brought into the intestine, is not yet done with; advantageous use can still be made of it. It can aid in the introduction of fats through the villi into the lacteals, and, from its combustible nature, is of an equal value to the system with the oils it thus helps to introduce. We may advantageously trace the course which it follows, for in so doing we shall complete our description of the function of absorption in its most general sense.

Return of a part to the intestine.

The fat matters which have been subdivided into portions of microscopical minuteness, small globules, each of which is coated over with a delicate film of albumen, and all brought therefore into the state of an emulsion, can make their way by reason of the peculiar properties of the investiture which thus covers them through the pores of the villi into the lacteal. For my own part, I do not believe that there is any passage through the epithelial cells, but that it is entirely interstitial, and that it is not unlikely that the biliary constituent aids in this progress. It signifies nothing that the spaces through which the fat globules have to go are less than their own diameter; they can elongate into worm-like forms, just as, under the same circumstances, blood-cells can do, and, the moment they reach the cavity of the lacteal, reassume their sphericity by reason of their cohesion. The albumen that now accompanies them in the liquid form, as the other chief ingredient of the chyle, comes, for the most part, from the blood-vessels of the villi. The chyle moves onward to the mesenteric glands, and makes its passage through them either in naked tubes or through their pulpy structure, is submitted to cell action and to arterial blood, undergoes the morphological changes which have been described in the preceding chapter, and, gaining the thoracic duct, is brought into the general circulation.

Manner of action of the villi.

In the description here offered of the function of absorption, the agency of physical forces alone has been considered, and these I conceive to be abundantly sufficient to enable us to account for all the phenomena.

CHAPTER VII.

OF THE BLOOD.

The Offices and Relation of Blood in the System.—The Plasma and Cells.—General Properties and Composition of the Blood.—Quantity in the Body.—Coagulation.—Blood-cells.—Their successive Forms.—The perfect Cell.—Hæmatin: its Properties.—Number of Blood-cells.—Plasma: its Composition, and Variations of its Ingredients.—Albumen, Fibrin, Fat, Sugar.—Mineral Ingredients of the Cells and Plasma compared.—Gases of the Blood.—Changes occurring during the Circulation.—General Functions of the different Ingredients of the Blood.—Introduction of Oxygen by the Cells.—Their transient Duration.

IT is necessary for the functional activity of every organized being that there shall circulate through all parts of it a nutritive liquid. In plants, it is the sap; in animals, the blood.

Since the life of plants manifests itself, for the most part, in a purely formative result, and involves little or no destruction of parts, the circulating current is devoted almost entirely to nutrition. But in animals, whose conditions of existence involve extensive and unceasing destruction, the current is burdened with another duty. It is also the means of removal of dying or wasted portions.

The blood: its functions.

In the first chapter it was shown that about a ton and a half of material is required by a man in the course of a year, and that in the same period a like amount is removed from the system. When we reflect that the introduction and removal of this immense mass is accomplished through the agency of the circulating blood, it is obvious that that fluid must be undergoing the most rapid changes. The rapidity with which dying matters are removed is strikingly illustrated by the minute extent to which they are permitted to accumulate in a healthy state. These elements of decay are strained off or exhaled as quickly as they arise. That fancied power, the "vis medicatrix naturæ," is only an ideal expression of the perfection with which the various eliminating mechanisms work. Poisonous agents, whether they have been introduced from without or have originated from morbid actions within, like all other useless or noxious products, find their proper channel of escape, and the system will thus rid itself of intoxicating liquids and narcotic drugs if their quantity does not exceed the amount that it can destroy or excrete in a special period of time.

Introduction and removal of material by the blood.

Considered in its relation to nutrition, the circulating liquid presents many interesting aspects. Each of the thousand variously-constituted parts of the body is withdrawing the supplies it needs: the muscular, the

Interconnection of all parts through this circulation.

nervous, the cartilaginous, the bony; and hence there arises a general balance in the system, each part making its demand at a certain rate, and each observing a complementary action to all the rest. Many of those phenomena which, in the infancy of physiology, were regarded as instances of sympathy between different parts, are clearly dependent on these conditions; for the development of one part, by abstracting special material from the circulating liquid, permits the co-ordinate development of another, or perhaps puts a stop to it. The minutest portion of the mechanism is thus indissolubly connected with all the rest through the medium of the blood.

The plasma and cells.

Seen as it circulates in the vessels, the blood consists of a colorless liquid containing corpuscles. In man, some of these corpuscles are white and others red. To the liquid in which they float, the designation of the plasma is given; the colored corpuscles, from their shape, are called discs or cells.

Properties of the blood.

The specific gravity of the blood varies from 1.050 to 1.059, the variation being, to a considerable extent, due to variations in the quantity of the cells. The temperature is about 100° Fahr., the reaction always alkaline; there is also a faint sickly odor, which differs in different animals. The capacity of blood for heat is in direct proportion to its density. The cells give to the blood its tint of color, and this, in the systemic arteries, is crimson, in the veins, deep blue. However, the color of arterial blood depends considerably on the condition of respiration. An imperfect introduction of oxygen, as in hot climates, causes the arterial blood to assume a dark color, and the same is observed when chloroform, ether, or diluted irrespirable gases are breathed. The blood of the male sex is heavier than that of the female.

Constitution of the Blood.

Water		784.00
Albumen		70.00
Fibrin		2.20
Discs	Globulin	123.50
	Hæmatin	7.50
Fats	Cholesterine	0.08
	Cerebrine	0.40
	Seroline	0.02
	Oleic and margaric acid Volatile and odorous fatty acid Fat containing phosphorus	0.80
Salts	Chloride of sodium	3.60
	Chloride of potassium	0.36
	Tribasic phosphate of soda	0.20
	Carbonate of soda	0.84
	Sulphate of soda	0.28
	Phosphates of lime and magnesia	0.25
	Oxide and phosphate of iron	0.50
Extract, salivary matter, urea, biliary coloring matter, accidental substances		5.47
		1000.00

Elementary Composition of dried Ox Blood.

Carbon	519.50
Hydrogen	71.70
Nitrogen	150.70
Oxygen	213.90
Ashes	44.20
	1000.00

This table leads to the hypothetical formula of the ultimate constitution of blood:

$$C_{48}\, H_{39}\, N_{6}\, O_{15}$$

As to the quantity of blood in the circulation, it has been variously estimated. It may perhaps be taken at one eighth of the weight of the body, a number which is agreed upon by several authors, and in support of which Lehmann mentions the following interesting observation: "My friend, E. Weber, determined, with my co-operation, the weights of two criminals before and after decapitation. The quantity of blood which escaped from the body was determined in the following manner: Water was injected into the vessels of the trunk and head until the fluid escaping from the veins had only a pale red or yellow color. The quantity of blood remaining in the body was then calculated by instituting a comparison between the solid residue of this pale red aqueous fluid and that of the blood which first escaped. By way of illustration, I subjoin the results yielded by one of the experiments. The living body of one of the criminals weighed 60,140 grammes; and the same body, after the decapitation, 54,600 grammes; consequently, 5540 grammes of blood had escaped. 28.560 grammes of this blood yielded 5.36 grammes of solid residue; 60.5 grammes of sanguineous water collected after the injection contained 3.724 grammes of solid substances. 6050 grammes of the sanguineous water that returned from the veins were collected, and these contained 37.24 grammes of solid residue, which corresponds to 1980 grammes of blood; consequently, the body contained 7520 grammes of blood (5540 escaping in the act of decapitation, and 1980 remaining in the body); hence the weight of the whole blood was to that of the body nearly in the ratio of one to eight. The other experiment yielded a precisely similar result."

Quantity of blood in the body.

A short time after it has been drawn, the blood undergoes coagulation, and is then said to be composed of the serum and the clot. In this state it is sometimes spoken of as dead. The plasma of living blood differs from the serum of dead in containing fibrin.

Spontaneous division into serum and clot.

The coagulation of the blood commences within about ten minutes after it has been drawn, and the clot undergoes a subsequent condensation during one or two days. To understand the physical nature of this singular change, we may conveniently regard the

The coagulation of blood.

living blood as containing three leading constituents—an albuminous liquid, fibrin dissolved therein, and the cells. The coagulation arises from the tendency of the fibrin particles to agglutinate together. As this takes place, the cells are caught in the meshes of the network that arises, and a voluminous red clot is the result. So the serum of dead blood contains no fibrin, and differs from the plasma of living blood in that important particular.

It has been observed that exposure to cold retards coagulation, as does likewise the absence of air, or covering the blood over with a film of oil. The condition of rest promotes it, as also does the presence of rough or angular bodies. Blood will yield up its fibrin readily when stirred with a stick. When, for any reason, the cells sink more rapidly than usual from the surface of the blood, the fibrin of the supernatant portion coagulates alone, giving rise to a stratum free from the red color, and designated the buffy coat, and on the subsequent contraction, since there are no cells to hinder the fibrin, its parts upon this stratum are drawn more closely together, and the clot becomes cupped.

The buffy coat.

By those who accept figurative expressions as an explanation of physiological facts, the coagulation of the blood is said to be due to its death; some, however, have regarded it as an abortive attempt at organization, and therefore a manifestation of life. Such contradictory explanations lose much of their interest when we examine the facts of the case critically. I believe that nothing more takes place in blood which has been drawn into a cup than would have taken place had it remained in the body. In either case the fibrin would have equally coagulated. The entrapping of the cells is a mere accident. The hourly demand for fibrin amounts to 62 grains; a simple arithmetical calculation will show that the entire mass of the blood would be exhausted of all the fibrin it contains in about four hours, so that the solidification of fibrin must be taking place at just as rapid a rate in the system as after it has been withdrawn. No clot forms in the blood-vessels, because the fibrin is picked out by the muscular tissues for their nourishment as fast as it is presented, nor would any clot form in a cup if we could by any means remove the fibrin granules as fast as they solidified.

Explanation of coagulation.

That blood-fibrin differs from muscle-fibrin in certain respects is to be admitted, but it does not follow that blood-fibrin is in a condition of retrograde metamorphosis. It may require modification before it can be received as the syntonin of muscles, but that such a conversion actually takes place I think there can be no doubt.

In entering on a detailed examination of the constitution and functions of the blood, our attention will have to be directed, in the first place, to the cells. It is sufficient to arrest our thoughts at once when we learn that for every beat of the pulse nearly twenty millions of these

organisms die! Physiology has its passing wonders as well as astronomy.

In the life of man there are three periods distinguished from each other by the nature or structure of the blood-cells. Those of the first period originate simultaneously with, or even previously to, the heart. These are sometimes designated as embryo cells, and in that view bear the same relation to those of the second period as do the lymph corpuscles to those of the third. They are colorless and spherical cells, containing granules of fatty material, and having a central nucleus. These are developed, by a process of internal deliquescence, into cells of the second period, which have acquired a red color, and in oviparous vertebrates an elliptical form, though in man they are circular. They are flat or disc-like in shape, have a diameter of about $\frac{1}{2500}$ of an inch, with a central nucleus of half that size. Sometimes they appear to undergo multiplication by division of the nucleus.

Successive races of blood-cells.

These cells of the second period are replaced by those of the third, the transition being clearly connected with the production of lymph and chyle corpuscles. By the end of the second month of fœtal existence the replacement is complete, and the class of cells or discs that has now arisen is continued during life. The mode of their production, according to Mr. Paget, is this. The chyle or lymph corpuscle loses its granular aspect, and acquires a pale red color, which gradually deepens; the corpuscle becomes smooth, loses its spherical form, and, condensing, takes on a convex lenticular shape, and eventually a bi-concave. While this change of structure is going on, the specific gravity increases through the condensation, and the development closes by the spherical, white, granular, lymph corpuscle becoming a red, bi-concave, non-nucleated, circular, small, and heavy blood disc.

The cell of the first period is therefore spherical, white, and nucleated; that of the second, red, disc-shaped, and nucleated; that of the third, red, disc-shaped, bi-concave, and non-nucleated.

The primordial cell advances in development to different points in different orders of living beings. The blood of invertebrated animals contains coarse granule cells, which pass forward to the condition of the fine granule cells, and reach the utmost perfection they are there to attain in the colorless nucleated cell of the first period of man. In oviparous vertebrated animals the development is carried a step farther, the red nucleated cell arising, and in them it stops at this, the second period. In mammals the third stage is reached in the red, non-nucleated disc, which is therefore the most perfect form.

Development of blood-cells in the animal series.

This perfect form of blood cell, as it occurs in man, may be described as presenting a flattened shape; the bright spot, which is sometimes seen in the centre, arising from a refraction of light due to the form of the

disc and not to a nucleus. The sac of each disc is elastic, so that it can be swollen by water until it becomes convex or even globular, or by immersion in thick sirup may be made to shrink, effects arising from the endosmotic infiltration or exudation through its wall. When passing through the fine capillaries in the course of the circulation, the cell, by reason of this elasticity, can make its way through very difficult passages, extending itself into a cylindroid form, or by bending, but it recovers its original shape as soon as relieved from pressure. The average diameter of the cell is estimated at $\frac{1}{3200}$ of an inch, the extremes being $\frac{1}{2800}$, and $\frac{1}{4000}$. The thickness of the cell is about $\frac{1}{12400}$ of an inch. The cell owes its color to hæmatin, which exists in its interior in a state of solution, and associated with globulin.

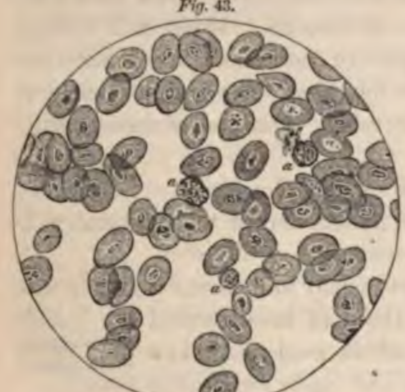
Properties and size of the perfect blood-cell.

Fig. 42.

Human blood-cells magnified 500 diameters.

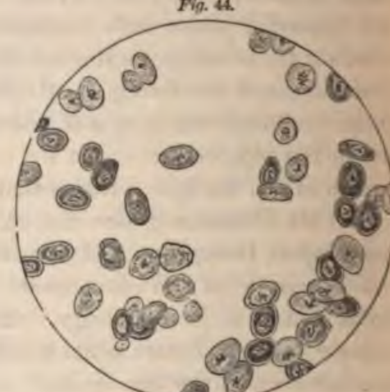
The facts mentioned in the preceding paragraph are illustrated by the annexed engraved photographs. *Fig.* 42 represents human blood-cells. Their form is circular: they have a central depression, but no nucleus. *Fig.* 43 represents the elliptic nucleated blood-cells of the frog, with here and there, at *a a*, chyle corpuscles. *Fig.* 44 represents the endosmotic action of

Fig. 43.



Elliptic blood-cells of frog magnified 250 diameters.

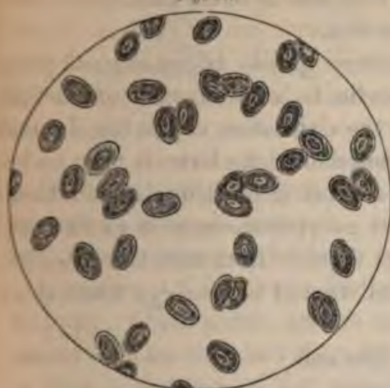
Fig. 44.



Action of water on elliptic cells.

water on these cells. *Fig.* 45, the action of acetic acid in darkening or concentrating the nucleus. In *Fig.* 46 we have an illustration of the size and appearance of the blood-cell in a reptile, the photograph from which this figure was taken having been made under the same magnifying power as that employed in obtaining the photograph of human blood.

Fig. 45.



Action of acetic acid on elliptic cells.

Fig. 46.

Reptile blood-cells magnified 500 diameters.

The mammals in which the blood corpuscles are not round, but elliptic and bi-convex, are the camel, the dromedary, and the llama. In birds and amphibia they are oval. The difference in the shape and size of these cells is of the more importance, since observations and measurements by the microscope may lead us to a correct reference of a sample of blood to its origin when chemical analysis would afford us no assistance. It is not to be forgotten, however, that both in size and form a blood-cell undergoes changes according to unequal pressures exerted upon it, or to the physical circumstances under which it is placed, liquid readily finding its way into its interior or exuding therefrom according to the laws of endosmosis, the elastic sac perfectly accommodating itself to these changes. As a consequence of these modifications, there will, of course, follow variations of specific gravity in the cell, differences in its tendency to sink in the plasma which surrounds it, and also differences in its tint of color.

Variations of the form of blood-cells.

By Mr. Wharton Jones, the colored blood-disc of the mammalian is regarded as being homologous with the nucleus of the colorless corpuscle of the same blood, and it may therefore be spoken of as a free cellæform nucleus, the cell itself having deliquesced or become disintegrated, and the nucleus, filled with globulin and coloring matter, remaining.

Human blood-disc is a cellæform nucleus.

The cell wall of the blood-cells is generally admitted to be fibrin, or some substance allied thereto; but there has been much difference of opinion respecting the constitution of the nucleus of those cells which possess it. By some, this also has been regarded as fibrin; by others, as fat; and by others, as a species of horn, to which the designation of nucleine has been given.

Nature of the cell walls and nucleus.

The cell wall of the white corpuscles does not appear to be elastic. It is viscid, and hence these bodies tend to agglutinate with one another:

in aspect it is granular. The contents appear to be an albuminous solution, in which fine granules are suspended.

Source of iron.

Though we have described the mesenteric glands as the original place of formation of the blood-cells, it is to be understood that these become perfected in the circulation of the blood; and from what will be said respecting the function of the liver, it may be inferred that that gland is the seat of a most important change: there probably they receive their iron. That no special organ is exclusively charged with the duty of forming them appears from this, that the first form of blood-cells arises in the germinal area of the embryo when there is, as yet, no gland.

Composition of Blood-cells.

Water	688.00
Hæmatin (including iron)	16.75
Globulin and cell membrane	282.22
Fat	2.31
Extractive	2.60
Mineral substances	8.12
	1000.00

Leaving the water out of consideration, the predominating ingredients of blood-cells are therefore globulin and hæmatin. The former is a substance approaching, in properties, to casein, or perhaps intermediate between casein and albumen. Its constituents, as determined by an ultimate analysis, are the same as in the case of those bodies.

Changes of color depending on change in the form of the cells.

Hæmatin is distinguished by its red color. When isolated, it exhibits the changes of tint characteristic of arterialization in a doubtful manner. There are, however, many facts which lead to the supposition that the color of arterial and venous blood does not depend so much on a chemical change in the hæmatin as on an alteration of the figure of the discs.

Properties of hæmatin.

The constitution of hæmatin is C_{44}, H_{22}, N_3, O_6, Fe. It exists under two forms, soluble and coagulated. It has hitherto been studied only in the latter state, and is soluble in weak alcohol acidulated with sulphuric or hydrochloric acid, but not in water. Its solution is therefore precipitated by the addition of that liquid. In weak solutions of alkalies it readily dissolves. Formerly its characteristic red color was attributed to the iron it contains, but that metal may be entirely removed from it without changing its tint. The amount of iron it yields is about seven per cent.

Hæmatin occurs in the blood-cells associated with globulin, and would seem to owe its origin to the action of the wall of the cell, if it be true that the red cells originate from the white ones. In this formation of hæmatin there are several reasons which lead us to infer that fat takes an essential share.

Ultimate Analysis of Hæmatin.

Carbon	653.47
Hydrogen	54.45
Nitrogen	103.96
Oxygen	118.81
Iron	69.31
	1000.00

The remarkable feature in the composition of this body is the large quantity of iron it contains. The percentage amount of this metal in the blood of the fœtus is much greater than in that of the mother. After birth the proportion declines, but it rises again at puberty. These variations in the amount of the iron are, however, dependent on corresponding variations in the amount of cells.

Iron in the cells.

The importance of the remark, when we arrive at the study of the bile, justifies us in repeating that the iron of the blood belongs to the hæmatin of the cells, its percentage proportion varying with their condition, and also with the region of the circulation from which they have been drawn. As derived from different animals, the cells present different quantities of this metal. Thus Schmidt found in 100 parts of dry blood-cells in man, 0.4348; in the ox, 0.509; in the pig, 0.448; and in the hen, 0.329.

The crystalline substance of blood occurs under three different forms, in prisms, tetrahedra, and hexagonal tablets. In the prismatic form it is derived from human blood, that of fishes, and of some mammals; in the tetrahedral form it is obtained

Crystalline substance of blood.

Fig. 47.

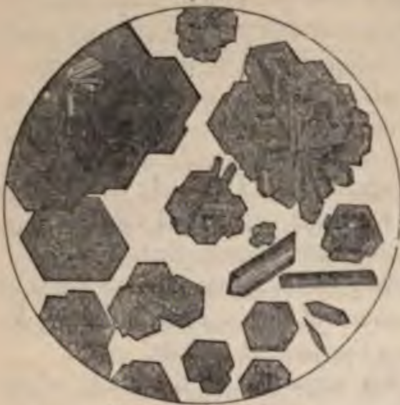
Human blood-crystals.

Fig. 48.

Blood-crystals of Guinea-pig.

from Guinea-pigs, rats, and mice; in the hexagonal form, from squirrels. Blood-crystals are of a red color, without smell or taste, losing their water of crystallization under exposure to the air, the different forms presenting different rates of solubility; the tetrahedral being soluble

Fig. 49.



Blood-crystals of squirrel.

in 600 parts of water, the prismatic in 90 parts only; the solution in the former case being pinkish, that of the latter, dark red. They are also dissolved by acetic acid, the red prussiate of potash producing a precipitate therefrom, as in the case of other protein bodies. Chlorine decolorizes their solutions and gives a white flaky precipitate. The crystals, when heated, swell, yield an odor like burnt horn, and, after combustion, leave a small quantity of ash. From the difficulty of obtaining blood-crystals in a state of purity, their constitution is not known with absolute certainty. The ash which they yield consists of about 72 per cent. of oxide of iron, and 21 per cent. of phosphoric acid, the protein constituent being apparently identical with other protein bodies. The crystals may be obtained for examination by covering a minute drop of blood with a glass slide, and, after adding water, alcohol, or ether, to permit a gradual evaporation to ensue. The amount thus produced depends very much upon the presence of light; thus Lehmann found that while he could only obtain two per cent. of crystals from the blood of the Guinea-pig in the dark, he could obtain more than seven per cent. in the sunlight.

Mode of obtaining blood-crystals.

Lehmann believes that the crystalline substance is not a mixture of a pigment and a protein body, but a pure chemical compound, having either a salt-like or conjugated constitution.

Color of blood-cells may depend on their form.

The color of the blood, as dependent upon the tint of its cells, is, according to the views of Henle, connected to a considerable degree with the form of those organisms as they vary from a concave to a convex surface, and not with the state of the hæmatin. When they are more concave they are of a crimson, when of a more convex, of a darker hue. Moreover, during these variations their investing membrane must necessarily change in thickness, and this likewise must alter their mode of transmitting light.

Among the causes which can impress a change on the figure of the blood-cells ought particularly to be specified exposure to oxygen and carbonic acid respectively, the latter causing them to become more opaque in their centre, broader upon their edge, the cell distending; an opposite effect ensuing under exposure to the former. In the case of the blood-cells of frogs exposed to oxygen, the long and short diameters both diminish, and the wall becomes granular; after exposure to carbonic acid they increase, the wall becoming pellucid.

Constituted thus of an elastic sac filled with globulin and hæmatin, the cells float in the plasma. They are nourished at its expense, and when they die, deliver up their contents by deliquescence to it. Accompanying them are the white corpuscles, from which new generations are to arise. It is usually stated that for every 50 red discs there is one white corpuscle. They may be readily discovered during the circulation by the microscope, many of them occupying the exterior of the current, as though they had a special relation to the soft tissues. It may perhaps be erroneous to regard these large white corpuscles as the embryos of the red discs. Reasons could be assigned in support of the doctrine that the same primitive germ going onward to development may, at a certain point, diverge in two directions; if it passes through one, it will perfect itself as a white cell; if through the other, as a red disc.

The white corpuscles.

The proportional number of blood corpuscles in different animals varies considerably. Generally cold-blooded mammals present fewer than warm-blooded ones, birds having more than quadrupeds, and among these the carnivora more than the herbivora. Of different domestic animals, the pig, the dog, the ox, the horse, the cat, the sheep, the goat, possess them in the order in which their names have been mentioned, the goat having only 86 to 145 in the pig. Their proportional number also varies in different regions of the circulation; thus it is said that arterial blood contains fewer than venous, the portal blood fewer than the jugular, the hepatic more than the portal. It is not, however, to be overlooked, that in all these determinations the quantity of water which chances to be present controls the estimates, and that therefore, as thus offered, they are really of less interest than might at first sight be supposed.

Number of cells in the blood of different animals.

We have next to speak of the plasma. It may be described as a clear and slightly yellowish colored fluid, consisting, as all animal juices do, for the most part of water, holding in suspension or solution albumen, fibrin, fats, and various mineral bodies, as the following analysis shows.

Composition of plasma.

Proximate Composition of the Plasma.

Water	902.90
Albumen	78.84
Fibrin	4.05
Fat	1.72
Extractive	3.94
Mineral substances	8.55
	1000.00

Of the water it may be remarked, that the usual percentage estimate made of its quantity, as regards the entire blood, is from 700 to 790 parts in 1000. Within these limits it is

Water of the whole blood: its variations.

liable to rapid variations, as dependent on the condition of thirst or the recent indulgence in drinks. It does not increase in proportion to the amount which has been imbibed, for the Malpighian bodies of the kidney, as will hereafter appear, strain it off with great rapidity. When the blood-vessels are distended to a certain degree, they refuse an entrance to it. The necessity of these provisions arises from the fact that there is a certain state of viscidity which the blood must possess for its proper circulation.

Respecting variations in the amount of water in the blood, it may be stated that that of women contains more water than that of men. Among different animals, the serum of the amphibia contains the largest quantity; and among mammals, that of the herbivora more than that of the carnivora. Obtained from different vessels, the arterial has more than venous blood, but the serum of the portal vein contains more than that of any other vein, the proportion depending on the amount and time of the ingestion of water.

Variations in quantity of albumen.

The albumen varies in quantity from 60 to 70 in 1000. It is probably associated or combined with soda. It exists in the blood of the splenic and hepatic veins as the neutral albuminate of soda. It does not appear to contain any phosphorus, as was at one time supposed. It is the plastic material from which all the soft tissues are nourished, and by it the cells themselves grow. Fibrin arises from it in the blood in the same manner as it does during the incubation of an egg; every care is taken to economize it in the system, and it is never excreted except in disease.

The quantity of albumen is greater in venous than in arterial blood, the proportion increasing during digestion. It also presents variations in different states of disease. Its condition varies in various parts of the circulation, a circumstance, to a considerable extent, due to the nature of the salts, or to the quantities of alkali with which it is associated.

Variations in the quantity of fibrin.

The fibrin is usually estimated at 2 or 3 parts in 1000 of blood. It may fall as low as 1, or rise as high as 7½. There is a constant drain upon it for the nutrition of the muscular tissues; and since it originates in the action of oxygen upon albumen, we should expect, as is really the case, that arterial blood would be richer in it than venous. The portal blood contains it in minimum quantity. Its percentage rises if oxygen be inhaled, or the respiratory process be quickened; for similar reasons, it uniformly increases in acute inflammations. The ultimate analyses of fibrin seem to show that it contains more oxygen than albumen, and this corresponds with its mode of origin. It is an important practical observation, that though it is easy to regulate the quantity of cells by variations of diet, the amount of fibrin can not so readily be changed in that manner, nor its development

checked by venesection. There is less fibrin in the blood of the carnivora than in that of the herbivora.

It has been asserted, as was mentioned before, that there is so wide a difference between the fibrin of blood and muscular fibre, that we can no longer regard the latter as arising from the former, but must consider it merely as coagulated albumen; and that, since the action of acetic acid upon it shows its relation to gelatine, it is probably more nearly related to the fibro-gelatinous than to the cellulo-albuminous tissues. But, although the fact that fibrin contains more oxygen than albumen seems to lend weight to such views, since oxidation appertains to the retrograde rather than to the ascending metamorphosis, there are so many arguments in favor of the old doctrine, that I think it may be regarded as thus far unshaken. Moreover, it is now established beyond any doubt, that by nitrate of potash, and other salts, fibrin may be transmuted into a substance analogous to albumen.

Fibrin is a histogenetic body.

The fats vary very much in quantity at different times. The amount is usually stated at from 1.4 to 3.3 in 1000 of blood. After a meal the plasma may be actually milky, through the fat globules brought in by the chyle. We have already shown that starch will give origin to fat, and oily substances can be obtained from lactic acid itself. The nitrogenized bodies, during their destruction, likewise yield them, and it is a normal function of the liver to effect the production of fat.

Variations in the quantity of fat.

The serum contains only an insignificant quantity of free fat; but there is a large proportion of saponified fat in it, as well as the lipoids cholesterine and serolin.

The view heretofore taken, that this class of substances is not histogenetic, but only respiratory, requires to be modified. There is reason to believe that the blood-cells themselves can not be formed except in presence of oil, which is also necessary to enable nitrogenized bodies to assume the ferment action. The nuclei of cells contain fats, as do also embryonic structures generally. Cholesterine, or liver-fat, is not saponifiable. It appears as a product of disintegration, increasing in quantity during acute diseases. The proportion of this substance increases after 40 years; it also forms a principal ingredient in biliary concretions.

Uses of the fats of blood.

Among the special constituents of certain portions of the venous blood not mentioned in the preceding tables, we ought not to overlook sugar, which exists as a constant ingredient of the blood contained in that part of the circulation intervening between the liver and the lungs. This, which is known as liver-sugar, may have originated in the transmutation of cane-sugar, or from the metamorphosis of the muscular tissues. It is to be remarked that the blood contains no gelatine.

Liver-sugar.

Comparison of the mineral constituents of the cells and plasma.

To the mineral substances in the cells and plasma of the blood respectively, attention should be particularly directed, since they indicate the functions of these portions.

Mineral Constituents in 1000 Parts of the Blood.

	Cells.	Plasma.
Chlorine.	1.686	3.644
Sulphuric acid	0.066	0.115
Phosphoric acid	1.134	0.191
Potassium	3.328	0.323
Sodium	1.052	3.341
Oxygen	0.667	0.403
Phosphate of lime	0.114	0.311
Phosphate of magnesia	0.073	0.222
Iron excluded	......	......
	8.120	8.550

The amount of inorganic matter in the cells and plasma, respectively, of 1000 parts of blood being nearly the same, the table shows that there is more than twice as much chlorine, and more than three times as much sodium in the plasma as in the cells. It may thence be inferred that the chloride of sodium is, for the most part, in the plasma. Moreover, there is six times as much phosphorus, and more than ten times as much potassium, in the cells as in the plasma; and therefore it may be inferred, since potash is required to so great an extent in the nutrition of the muscular system, and phosphorus as an element of the phosphorized oils in the nervous, that the cells have a direct functional relation to those important mechanisms, and this in addition to their duty of introducing oxygen.

Functions of the mineral constituents of the blood.

The mineral constituents of the blood discharge very different duties, some, either directly or indirectly, acting functionally, others as histogenetic bodies. Thus the alkaline properties of the blood are due to the presence of the carbonate and phosphate of soda, and this latter substance enables the serum to hold in solution carbonic acid, and thus it maintains a relation in the respiratory operation. But the phosphate of lime discharges a true histogenetic function, since upon it the bony system depends for its nutrition. The mutual relations of these substances are, of course, very complex, though often of importance. Thus, of the two just mentioned, the phosphate of soda enables the serum to hold the phosphate of lime in solution.

Coloring matter of serum.

The tawny coloring matter of serum differs from cholepyrrhin in not yielding the characteristic reaction of that body. The tint sometimes becomes quite deep, owing to several different causes, such as the undue accumulation of the coloring matter of urine, through disturbance of renal action, or from bile pigment, as in icterus.

The gases which can be disengaged from the blood occur in the cells, according to Magnus, a statement which, however, is very far from being

substantiated: they are carbonic acid, oxygen, and nitrogen. He found that this liquid can absorb once and a half its volume of carbonic acid, and that in arterial blood the proportion of that acid to oxygen is as 16 to 6, in venous as 16 to 4. That the oxygen is very loosely retained is shown by the circumstance that it may for the most part be removed by exposure in a vacuum. The other gases may be withdrawn by a stream of hydrogen.

Gases of the blood.

At a temperature of 98°, water absorbs scarcely one per cent. of its volume of oxygen gas, but the blood can take up from 10 to 13 times as much. This is accomplished by the coloring material. The amount is independent of variations in the pressure of the air, which would not be the case if the gas were received into the circulating fluid by mere solution. This is the opinion of Liebig, by whom it is regarded as being to some extent substantiated by the fact that the respiration is accomplished with nearly the same result, so far as the absorption of oxygen is concerned, at considerable heights above and at the level of the sea, and that no more oxygen is received from an atmosphere very rich in that gas than from the ordinary air. However correct this view may be, the facts cited in its support are very far from being undeniable.

The preceding chemical examination of the special constituents of the blood leads us next to consider the general functions of this liquid in the aggregate.

In this general sense, the blood discharges the following offices. Its albumen has the duty of giving origin to all the plastic tissues of the system. From it, for example, by cell action, as explained in treating of lacteal absorption, fibrin arises—fibrin, which is used for the renovation and repair of the muscular tissues. The discs have a relation with the function of respiration; they obtain oxygen in the pulmonary circulation, and carry it through the system. They contribute, moreover, to the development of muscular fibre, and also nervous material, and this not alone as regards the coloring matter of those tissues. The fats are necessary in the production of fibrin and for the nuclei of cells; but, besides these histogenetic relations, they eventually, with the exception of liver-fat, undergo oxidation, and so minister to the support of a high temperature. Of the saline substances, common salt promotes digestion by aiding in the preparation of gastric and pancreatic juices; the phosphate of soda enables the plasma to hold carbonic acid in solution, and carry it to the lungs.

General statement of the functions of the different constituents of the blood.

It is interesting to observe the limits of variation which the blood may present in disturbed or diseased conditions. In inflammations, the fibrin may increase fourfold; in typhoid fevers it may diminish to less than one half, and from these variations special results may arise. Thus diminution of its fibrin disposes the blood to preternatural oozing or fa-

cility of escape. So also the cells have been known, in cases of chlorosis, to sink to one fifth of the healthy amount. The albumen, too, exhibits like variations. In Bright's disease it greatly diminishes, much of it escaping in the urine by the straining action of the kidneys.

Changes occurring during the circulation.

Thus constituted, the blood, by a mechanism to be described in the next chapter, passes from the heart alternately to all parts of the system, and alternately to the cells of the lungs, giving rise to what have been termed the greater and less circulation, or the systemic and the pulmonary. In the systemic circulation, the blood, which leaves the heart in an arterialized condition, or associated with atmospheric oxygen, gives up that element to the various tissues as it pervades them, and accomplishes a double result: the removal of all those particles which, having discharged their duty and undergone partial or perfect interstitial death, are ready to pass away, and also the liberation of a great amount of heat by the destructive oxidation; so, at the same time, the wasted matter is removed and advantage taken of it to raise the temperature of the body. This done, the blood makes its way back to the heart, following the channel of the veins as they successively converge into trunks that are larger and larger. At the moment of surrendering its oxygen and receiving the various products of combustion, a change of color occurs. The bright crimson turns to a deep blue, and the blood presents itself of that color at the heart.

It now undergoes the less or pulmonary circulation. Leaving the heart, it passes over the air-cells of the lungs, and is there exposed to the aerating action of the atmosphere. From the interior of the cells the discs receive their supply of oxygen, the plasma surrendering up carbonic acid and the vapor of water. The color now changes back from the blue to the scarlet. In this condition it returns to the heart, to be distributed in the systemic circulation once more.

Less obvious but important changes.

During this double round an incessant change is taking place in the constitution of the blood: it is undergoing a continuous metamorphosis. In some respects, as, for instance, in color, this is obvious enough. But the invisible changes infinitely exceed in importance and amount those that are obvious to the eye.

All the soft tissues, since they are wasting away, require repair. This, inasmuch as it is accomplished either directly or indirectly by the albumen of the blood, gives rise to a constant drain of that substance, and demands a constant supply, which is provided by nutrition or stomach digestion.

Translation of oxygen by the cells.

The cells, which constitute the other chief portions of the blood, are necessary to the production of a high temperature, by constantly transferring oxygen from the cells of the lungs to every part of the body; carriers of oxygen they have been

truly called. That this is one of their duties has been proved experimentally, for a solution of albumen or the serum has but little power of absorbing oxygen, scarcely exceeding water itself in that respect, but the discs condense it at once. The change of color they exhibit as they alternately gain or lose that element, is in itself a proof of this fact, as is also the action of serum or blood-discs respectively on a measured volume of air contained in a jar. If the discs be in the venous or purple condition, they quickly absorb oxygen from the confined air, which therefore at once diminishes in amount, but the serum, or a solution of albumen, produces no such effect. The plasma serves, therefore, for the general nutrition of the system, and the discs, by transferring oxygen from point to point, discharge that part of their duty which is connected with the production of heat.

Transitory duration of the cells.

But the discs, though of a flattened form, are truly cells, and all that obtains in the case of cell life and cell action obtains for them. They have not a duration at all comparable to the duration of the system, but are constantly coming into existence and disappearing. Each is an individual having its own particular history, its time of birth, its time of maturity, its time of death. Each passes through a series of incidents proper to itself. Originating as has been described, they grow at the expense of the plasma, and in this regard it serves for their nutrition as well as for that of the body generally.

On exposing blood-cells to oxygen and carbonic acid gases alternately, there is not only a change in their shape, which becomes corrugated and star-like, but also in their chemical constitution, so that, after such an exposure of nine or ten times, they are entirely destroyed. Such alternations occurring in the system doubtless lead to the same result, though more slowly, since the oxygen is presented in a diluted condition.

Dying cells.

The corrugated and star-like blood-cells abound in the blood of the portal, though not in that of the hepatic vein. If their aspect arises from their tendency to disintegration, this is no more than might be expected in view of the functions of the liver. That the stellated aspect is an indication of a commencing disorganization, or other profound change, may be illustrated by an examination of the action of water on normal blood-cells, which, if they be exposed to that liquid, undergo a distention; their thickness increasing more rapidly than their diameter, they lose their concavity, become convex, and at last appear as spheres of a less size than the original discs. When

Fig. 50.

Stellated blood-cells magnified 500 diameters.

the quantity of water they have received has distended them to their utmost capacity, they then are invisible; but when it is withdrawn from them by establishing exosmosis through the addition of saline substances, they may reappear in the corrugated or star shape, as seen in the photograph, *Fig.* 50.

With respect to the action of the hæmatin, it may be observed, that other nitrogenized coloring materials present a similar relation to oxygen. As an example, indigo may be mentioned. I consider that the properties of this substance illustrate in a significant manner the properties of hæmatin in the system. Indigo occurs in the leaves of the plant which yields it in a yellow and soluble state. It is easily extracted from them by maceration in water. Exposed to the air, it absorbs oxygen, becomes insoluble, and simultaneously gains a deep blue tint. So lightly is the oxygen thus united to it, that by exposure to very feeble agents it surrenders it up, and repasses into the yellow and soluble condition. Once more exposed to the air, it turns blue, and once more may have that color removed from it by taking its oxygen away. For many times in succession its tint may be thus changed, and made yellow or blue at pleasure.

Action of hæmatin illustrated by indigo.

From this we perceive in what a loose manner oxygen is held by such a coloring material; how readily it surrenders it, and how readily it recovers it. Such a union can scarcely be called an oxidation or a combination; it is rather an association.

All this is precisely what occurs in the case of hæmatin. It takes up oxygen with rapidity as it goes over the cells of the lungs, and turns scarlet; it surrenders that oxygen with equal facility as it passes the systemic capillaries, and turns blue. This change of color is incessantly taking place; it is now red, and now blue, as the cells are passing in the greater and the less circulation.

Feeble union of oxygen and hæmatin.

Formerly it was supposed that, in the act of respiration, oxygen from the air united with carbon of the blood or of the cells, and carbonic acid formed, a combination or perfect oxidation taking place in the lung. But, if this were true, the temperature of those organs should be higher than that of the rest of the body, and this is by all admitted not to be the case.

Reception and transference of oxygen by the blood-cells.

The cells are therefore carriers of oxygen. They receive that vivifying principle as they move over the respiratory cells, and, freighted with it, pass to all parts of the body, not united with it, nor disorganized, nor burnt up by it, but holding it loosely, and ready to give it up and go back again for a fresh supply.

The sac containing the hæmatin offers no kind of resistance to these exchanges. It will be fully demonstrated in the chapter on respiration that this is the case. Thick pieces of India-rubber, stout animal mem-

branes, or even masses of stucco, present no obstacle to the passage of gases. The delicate wall of these cells, a tissue of almost inconceivable tenuity, can offer no resistance. The gas passes in and out without impediment or restraint.

Summary of the function of blood-cells.

But though in this manner these little organisms perform their duty, it is only for a time. They may take oxygen from the air-cells and give it up in the system, and do this perhaps many thousand times, but it comes to an end at last. The incessant motion stops, and the worn and exhausted disc is brought to its term. By degrees, as old age steals over it, it becomes corrugated and relaxed, is unable to withstand chemical reagents, as its younger comrades can do. Through the microscope it seems puckered and attenuated. The red color of its interior deteriorates into a tawny tint. As with a leaf in the autumn, the natural color of which disappears, and yellowness or other change precedes its fall, so with the dying disc. Unable any longer to discharge its duties, its existence is brought to a close, the decayed hæmatin is shed out to give a transient tawny tint to the plasma, but is presently strained off as one of the constituents of bile by the liver. Nor is the illustration here used wholly metaphorical, for, in the case of herbivorous animals, Berzelius has shown that the coloring matter of their bile is identical with chlorophyll, the coloring matter of leaves.

CHAPTER VIII.

OF THE CIRCULATION OF THE BLOOD.

The Heart as a Machine.—Inadequacy of Harvey's doctrine of the Circulation.—Physical Principle of the Circulation; applied in the case of a Nucleated Cell, Pervious Tissue, Motion of Sap and of Blood.—Dependence of the Circulation on Respiration.—Forms of Circulation: Systemic, Pulmonary, Portal.—Description of the Heart: its Movements.—Their Force, Number, and Value.—Sounds of the Heart.—Cause of its Contractions.—Description of the Arteries, Capillaries, Veins.—Explanation of the Circulation of the Blood.—Facts supporting it.—The First Breath.

No function of the animal mechanism illustrates more strikingly the doctrine that we must rely on physical agents for physiological explanations than that which we have now to consider, the circulation of the blood.

The heart as an engine.

We surrender some of the most beautiful recollections of classical mythology, and some of the most cherished popular illusions of our own times. The heart, which in the higher classes of life is the central organ of impulse of the circulation, is to be degraded into a mere engine. We have to speak of its valves, its cords, its pipes.

We have to consider its exhausting and its forcing action—to deal with it just as we should deal with any hydraulic apparatus. In the old times this organ was looked upon as the seat of the thoughts and the passions; it was the centre of all good and evil, purity and uncleanness, devotion and love. In the modern system the brain has succeeded to the functions which were once imputed to it.

The heart, then, is no longer an altar on which flames are burning, no longer the seat of the passions and the source of love. It is a machine, but what kind of a machine? How great is the admiration we may express at its exquisite construction! This little organ can execute three thousand millions of beats without a stop! In the course of a life, such as we sometimes meet with, it has propelled half a million tons of blood, and, though momentarily wasting, has repaired its own waste all the time. The mathematical rhythm of its four moving cavities, the perfect closure of its mitral and semilunar valves, and the regurgitating play of its tricuspid, have never failed it. To the eye of the intellect there is nothing lost in transferring it from the regions of metaphor and speculation to the domain of physical science.

Harvey's doctrine of the circulation of the blood.

The doctrine of the circulation of the blood was first propounded by Dr. Harvey about two hundred years ago. It originated in the discovering of the valves of the veins by Fabricius ab Aquapendente. After many years of discussion, it was reluctantly received by the medical profession.

In this doctrine the circulation is referred to causes that are purely mechanical, in the strictest acceptation of that term. The contraction of the walls of the heart propels the blood through the arterial tubes, and even through the veins, the direction of its movement being insured by a proper arrangement of valves.

Its imperfections.

But when comparative anatomy and physiological botany were more extensively cultivated, it was seen that this doctrine is insufficient, for the unity of nature forbids us to believe that nutritious juices are circulated in different tribes of life by different forces. And though it may be that the contractions of that central impelling mechanism regulate the circulation in those organisms which have a heart, what is to be made of those countless numbers which have none? In this group we find the whole vegetable creation, and a majority of the animal.

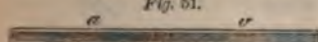
Physical principle involved in the capillary circulation.

There is a physical principle which has long appeared to me sufficient. Its use in an explanation of the motion of nutritive juices in organized systems of every class I have taught in the University for many years. It possesses the advantage of generality, since it is applicable in every case, from the circulation taking place in a closed cell up to that of man.

In Chapter VI. is a general statement of the phenomena and laws of capillary attraction; the principle now to be employed is closely connected therewith. It may be stated as follows:

If two liquids communicate with one another in a capillary tube, for the substance of which they have affinities of different intensities, movement will ensue: the liquid having the highest affinity will occupy the tube, and may even drive the other before it. The same effect will ensue in a porous structure.

Fig. 51.



Motion in a capillary tube.

Thus, let b, b, *Fig.* 51, be a capillary tube of any kind, which is occupied conjointly by two liquids, a and v, meeting each other in its middle, c; a having a high and v but little affinity for the substance of which the tube consists, a will occupy the tube, pressing out v before it. Of course, it is to be understood that the liquids a and v respectively communicate with reservoirs that can furnish them a necessary supply.

Applied to the explanation of endosmosis.

The various phenomena described under the designation of endosmosis are experimental illustrations of the same kind. Thus, when water is put on one side of a piece of bladder, and alcohol on the other, the water, having the highest affinity for the substance of which the bladder consists, occupies the pores thereof, and expels the alcohol. Nor would any of the latter substance find its way in the opposite direction, back into the water, were it not so soluble or diffusible in that liquid. Exosmosis therefore takes place through the water, and constitutes a very subordinate or feeble current.

Now it is precisely relations of this kind that are observed in the case of the circulating and nutritive juices of all organic beings.

Circulation in nucleated cells.

The simplest instance is presented by the fluid contents of certain nucleated cells, both among animals and plants, in which a current moves toward, and then from, the nucleus, coming back in a returning path. The fluid which the cell contains yields to the nucleus, in which seems to be concentrated all the activity of the organism, the nutritive material it requires, and, this done, passes on to make way for other portions. The act of nutrition, therefore, is followed by motion, and this upon the above simple principle; for the liquid, before it approaches to the nucleus, is charged with material which the nucleus can attract; but immediately after contact has taken place, and the material has been removed, the liquid maintains no longer any relation with the nucleus, the affinity or attraction is satisfied, and, so to speak, it loses its hold thereupon, and is pressed off by new-coming portions. Before its approach, and after its departure, the liquid has opposite relations to the nucleus, and in this respect may be regarded as representing two liquids, the one having a high affinity, and the other none, for the nucleus. The

Fig. 52.

Circulation in vegetable cells.

circulation in vegetable cells is shown by the direction of the arrows in *Fig.* 52. The course taken by the current may be determined under the microscope by the minute floating, or, rather, drifting granules. It is to and then from the nucleus.

Fig. 53 represents one of the jointed hairs from the Tradescantia Virginica. The engraving is from the view given by Mr. Slack, corrected, however, by the aid of a photograph of a similar object. *a*, *b*, *c*, *d* are the successive cells of the hair. The dotted lines show the direction of the current to and from the nucleus.

Fig. 53.

Circulation in Tradescantia.

Circulation through pervious parts.

The juice which is about to nourish a part has for that part a certain affinity, but, with the accomplishment of that nutrition, the affinity is at once lost. Thus, for instance, in the systemic circulation, the parts to be nourished have a certain affinity for the arterial blood; they take from it whatever their purposes require, and, that done, the relation at once ceases; the blood, become venous, has lost its hold upon them, and is pressed off. We may conveniently describe this effect as a pressure of the unchanged upon the changed liquid.

Explanation of the rise and descent of the sap of plants.

The motions of the sap in plants are clearly dependent on this principle. Leaving out of consideration the minor movements which take place for special purposes, or at specific epochs in the development, it may be truly said that the nutritive changes occurring in the leaf are the primary cause of the motion; for, as the ascending sap presents itself on the sky face of the leaf, it receives carbon, under the influence of the sunlight, from the air, and becomes converted into a gummy, glutinous liquid. And just as in the pores of a bladder, or in those of any pervious mineral, pure water will drive out gum-water, and occupy the pore, so will the ascending sap expel the gummy solution from the capillary tubes or intercellular spaces of the leaf. As fast as this takes place, the active liquid becomes inactive, by itself changing into a gummy solution, and the movement is perpetuated. And this ensues not only in the leaf, but in every part of the plant; the liquid to be changed presses upon that which has changed, and forces it onward. In this manner, motions in various parts and of very great intricacy will ensue, but all of them, if duly considered, no matter whether their seat be in the root or in the bark, in the flowers or in the

leaves, no matter whether they take place in the height of summer or just at the close of winter, when the sap first rises, or even in the germinating seed which is under the ground, and has never yet been exposed to the light, may, without difficulty, be referred to the nutritive change carried on in the leaves of the plant under examination, or its parent, by the influence of the rays of the sun.

All this holds good, not only in the nutrition of a cell, the more complicated nutrition of the various parts of a flowering plant, or even of an animal, but likewise in those destructive changes restricted to the latter class, and arising in interstitial decay; for the blood has a double duty to perform: it not only serves for nutrition, but also for the removal of effete and dying parts. These it effects the oxidation of, their carbon passing into carbonic acid, their hydrogen into water; and this is accomplished by the oxygen which has been obtained in the process of respiration. The scarlet or arterial blood, charged with its oxygen, passes to all parts of the economy in search of organic particles ready to be removed; it effects their disorganization, and, becoming thereby venous, is pressed onward. And now, if we recall that nutrition in animals depends on the access of air—even fibrin can not arise from albumen except under that condition—we can not avoid the conclusion that all operations of repair and all operations of waste are made to conspire together for the production of movement; and though every part offers its own special cause, as depending on nutrition, or disintegration, or secretion, they may be all grouped together as the necessary results of one more primitive operation, which is the supply of oxygen to the blood in the respiratory mechanism.

Explanation of the capillary circulation of animals.

In my view of this subject, it is therefore the arterialization of the blood in the lungs which is the cause of the circulation in man. I consider the circulation as the consequence of respiration; and though, in one sense, the minor causes are numerous, each portion of nervous material, each muscular fibre, every secreting cell working its own way, these subordinate actions are all referable to one primordial act, and that is the exposure of the blood to the air.

Dependence of circulation in the respiration.

Whatever, therefore, interferes with respiration, interferes with circulation. If an irrespirable gas is thrown into the cells of the lungs, the passage of the blood is instantly arrested, and asphyxia ensues. Or, if the access of the air is cut off, as in drowning, in vain the heart exerts its utmost convulsive throb—it is unable to drive forward the blood; and in those cases, by no means infrequent, yet undoubtedly the most surprising occurring in the practice of medicine—restoration from death after drowning, the whole success turns on one condition, the re-establishment of the arterialization of the blood.

Case of restoration from death by drowning.

If that be accomplished, the circulation is restored, and the heart proceeds with its duty. And for these reasons, I believe that in many cases success would be had, where failures are now experienced, if, instead of resorting to atmospheric air, pure oxygen gas or protoxide of nitrogen were administered.

In the more highly-developed organisms the objects of the circulation are threefold: 1st. To minister to the nutrition of the system; 2d. To introduce oxygen; 3d. To remove the products of waste. In man, these various results are accomplished by several different arrangements: 1st. The greater, or systemic circulation; 2d. The less, or pulmonary circulation; 3d. The portal circulation; 4th. The Malpighian circulation, &c.

Different classes of circulation.

The course taken by the blood is as follows. Leaving the left ventricle of the heart, it passes into the aorta, and is distributed by the ramifications thereof, constituting the systemic arteries, to all parts of the system. It moves onward through the capillaries, which may at once be considered as the terminal ramifications of the arteries and the commencing tubelets of the veins. These, converging into larger and larger venous trunks, the systemic veins, deliver it into the ascending and descending venæ cavæ, from which it flows into the right auricle, and from thence into the right ventricle of the heart. From thence it is driven into the pulmonary artery, to be distributed to the lungs, and, coming therefrom along the pulmonary veins, reaches the left auricle, and from thence it gains the left ventricle, which was its starting-point.

Course of the blood in its systemic and pulmonary circulations.

In the pulmonary veins, the left cavities of the heart, and in the systemic arteries, the blood is crimson. In the systemic veins, the right cavities of the heart, and pulmonary artery and its branches, it is blue. The change from crimson to blue takes place in the systemic capillaries, and from blue to crimson in the pulmonary. The systemic, or greater circulation, is considered as beginning at the left ventricle and ending at the right auricle; the pulmonary, or less circulation, begins at the right ventricle and ends at the left auricle. This double course is sometimes, among authors, illustrated by likening it to the figure 8, the upper loop representing the pulmonary, the lower the systemic circulation, and the heart placed at the nodal point.

Distribution of crimson and of blue blood.

As has just been remarked, there are other subordinate circulations, but of these only one need attract our attention at present—it is the portal. This originates in a system of capillaries, the veins belonging to the digestive apparatus, which, converging rapidly together, form a common trunk, the portal vein. This at once ramifies like an artery in the substance of the liver. From the resulting capillaries, the portal blood passes into the commencing capillaries of the hepat-

The portal circulation.

ic veins, which empty into the inferior vena cava, and so it reaches the general circulation. The physical peculiarity of the portal circulation is, that it commences in a capillary system, and ends in one, without the intervention of any central organ of impulse, or heart. At a very early period, comparative anatomists were struck with the analogy between the portal circulation in man and the systemic circulation of fishes, both being carried on in the same way, that is, without a heart. In fishes, the heart is a branchial, respiratory, or pulmonary one. Their systemic circulation, or circulation of crimson blood, commences in the capillaries of the respiratory apparatus, the gills; a convergence takes place into an aorta, which ramifies into systemic capillaries. So the great circulation in these tubes is accomplished without any heart. It is scarcely necessary to point out the bearing of such a fact on the theories of the movement of the blood.

Portal circulation illustrated by that of a fish.

Fig. 54.

Diagram of fish circulation.

In *Fig.* 54 is a diagram of the circulation of a fish; *a*, is the auricle; *b*, the ventricle; *c*, the branchial or pulmonary artery; *e*, *e*, the branchial or pulmonary veins, bringing blood from *d*, the branchiæ, and converging directly to *f*, the aorta, which distributes the systemic blood. This is collected into a vena cava, *g*, and so brought to the auricle, *a*. There is therefore no systemic heart.

The further discussion of this subject will be continued as follows: We shall describe, 1st, the construction and action of the heart; 2d, of the arteries; 3d, of the capillaries; 4th, of the veins. We shall then present a view of the combined result of these various mechanisms.

The heart.

1st, The Heart. The first appearance of the heart is as a cavity arising in a collection of cells, by deliquescence or separation of the central ones. At this early period, and even before the cavity has fairly formed, pulsation may be observed. The organ soon assumes a tubular form; and this, becoming curved, as shown in *Fig.* 55, differentiates into three compartments, with arterial and venous connections; 1, the venous trunks; 2, the auricle; 3, the ventricle; 4, the bulbus arteriosus. The form to be eventually assumed is foreshadowed in the manner in which the curved tube develops, the arch of the curve, 2, bulging so as to form a conical ventricle. This tri-chambered heart remains permanent in fishes, as seen in the preceding figure (54), of which *c* is the third chamber. But in birds and mammals, the aortic bulb merges into the ventricle, through which, as well as through the auricle, a septum or partition is established, and

Fig. 55.

Rudimentary heart.

Fig. 56.

Diagram of single heart.

thus a double heart, or one of four chambers, arises.

The diagram, *Fig.* 56, represents a double-chambered heart, *d* being its auricle, *e* the ventricle, *c, c,* the veins converging to the auricle, *a* the aorta or main artery passing from the ventricle. The course of the blood is indicated by the arrows.

The heart with four cavities may be considered as arising from the conjunction of a pair of the preceding form, with their efferent and afferent tubes, or arteries and veins, so modified or arranged that the right heart receives its blood from the system in an auricle, from which it passes into a ventricle, and thence to the lungs. From the lungs, after aeration, this blood is brought to the auricle of the left heart, thence into its ventricle, and thence to the aorta. Though all four chambers are generally coalesced into one conical form, the heart of the dugong, *Fig.* 57, presents the true typical structure; E is the right or pulmonary ventricle, L the left or systemic ventricle, their apices being quite apart; D is the right or systemic auricle, F the pulmonary artery, K the left or pulmonary auricle, and A the aorta.

Fig. 57.

Heart of the dugong.

Fig. 58 is the anatomy of the human heart as viewed upon the right side, the figure and description being from Dr. E. Wilson. 1, the cavity of the right auricle; 2, the appendix auriculæ; 3, the superior vena cava, opening into the upper part of the right auricle; 4, inferior vena cava; 5, the fossa ovalis; the prominent ridge surrounding it is the annulus ovalis; 6, the Eustachian valve; 7, the opening of the coronary vein; 8, the coronary valve; 9, the entrance of the auriculo-ventricular opening; *a*, the right ventricle; *b, c,* the cavity of the right ventricle, on the walls of which the columnæ carneæ are seen; *c* is placed in the channel leading upward

Fig. 58.

Human heart on the right side.

to the pulmonary artery, *d*; *e, f*, the tricuspid valve: *e* is placed on the anterior curtain, and *f* on the right curtain; *g*, the long columna carnea, to the apex of which the anterior and right curtains of the tricuspid valve are connected by the chordæ tendineæ; *h*, the long moderator band; *i*, the two columnæ carneæ of the right curtain; *k*, the attachment by chordæ tendineæ of the left limb of the anterior curtain; *l, l*, chordæ tendineæ of the fixed curtain of the valve; *m*, the valve of the pulmonary artery: the letter of reference is placed on the inferior semilunar segment; *n*, the apex of the right appendix auriculæ; *o*, the left ventricle; *p*, the ascending aorta; *q*, its arch, with the three arterial trunks which arise from the arch; *r*, the descending aorta.

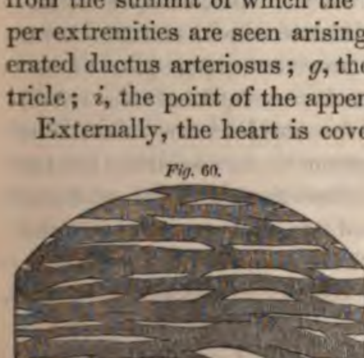
Fig. 59 exhibits the view of the organ on its left side. Like the preceding, the figure and description are from Dr. Wilson. 1, cavity of the left auricle: the number is placed on that portion of the septum auricularum corresponding with the centre of the fossa ovalis; 2, cavity of the appendix auriculæ; 3, opening of the two right pulmonary veins; 4, the sinus into which the left pulmonary veins open; 5, the left pulmonary veins; 6, the auriculo-ventricular opening; 7, the coronary vein, lying in the auriculo-ventricular groove; 8, the left ventricle; 9, 9, the cavity of the left ventricle. The numbers rest on the septum ventriculorum. *a*, the mitral valve: its flaps are connected by chordæ tendineæ to *b, b, b*, the columnæ carneæ; *c, c*, fixed columnæ carneæ, forming part of the internal surface of the ventricle; *d*, the arch of the aorta, from the summit of which the three arterial trunks of the head and upper extremities are seen arising; *e*, the pulmonary artery; *f*, the obliterated ductus arteriosus; *g*, the left pulmonary artery; *h*, the right ventricle; *i*, the point of the appendix of the right auricle.

Fig. 59.

Human heart on the left side.

Externally, the heart is covered by a serous membrane, pericardium, and in its interior is sheathed by the endocardium, an extension of the interior coat of the great blood-vessels. Though its movements are wholly involuntary, its muscular fibres are of the transversely striated kind. They are about one third less in diameter than those of voluntary muscles generally,

Fig. 60.



Muscular fibres of the heart.

and are especially characterized by their disposition to anastomose with one another, as represented in *Fig.* 60. In the ventricles, the arrangement is such that the fibres of the external and internal surfaces decussate.

The motions of the heart consist in the relaxations and contractions of the muscular walls of its cavities. The two auricles contract at the same moment, as do also the two ventricles, but the contractions of the auricles coincide with the relaxations of the ventricles.

Relaxations and contractions of the heart.

The course of the blood through the heart is this. The venous blood, brought by the ascending and descending cavæ, flows into the right auricle as it is dilating, and for the moment pushes forward to the ventricle, but the auricle, being of less capacity than the ventricle, is filled to distention first; at this instant it contracts, forcing its contents past the tricuspid valve into the ventricle, and fills it completely. The blood can not regurgitate into the veins to any extent while this is going on, because of the almost perfect closure of their valves. The right ventricle now commences to contract; its fleshy columns shorten so as to pull upon the tendinous cords attached to the flaps of the tricuspid valve: this enables the blood to get behind them, and they quietly close the aperture between the auricle and ventricle; the closure is not, however, under all circumstances, perfect, the mechanism being such as to permit leakage or regurgitation to a limited extent. The blood now rushes into the pulmonary artery, passing by its semilunar valves, which, the moment the ventricular pressure ceases, shut, so as to prevent any return to the heart.

Course of the blood in the heart, and movements of the valves.

Having passed through the lungs and been submitted to the air, the blood now returns to the left auricle, which forces it into the left ventricle, the action on this side of the heart being the same as on the other; the mitral valve, which closes the opening from the auricle into the ventricle, is worked in the same manner as the tricuspid, and the blood is pressed into the aorta, the semilunar valves of which, at that instant, shut abruptly with an audible sound, and prevent any regurgitation. In this manner the distribution to the system is accomplished.

On both sides of the heart, as soon as the auricles have finished their contraction, they begin to dilate, and continue to do so during the period that the ventricles are contracting. Thus there is an accumulation in them when the ventricles are ready to dilate, and, as soon as that occurs, the blood flows freely forward into those cavities, the complete distention of which is then accomplished by the contraction of the auricles, as before explained.

Movements of the auricles and ventricles.

The mode of action of the two sets of cavities is different. The auricles contract suddenly, first at the place of junction

of their veins, the effect passing quickly forward; the ventricles contract more slowly, but simultaneously in every part.

During each beat of the heart two sounds may be heard, followed by a silence. The first sound is dull; the second, which follows it quickly, is sharp. They may be imitated by articulating the syllables lubb, dup. The first is due to the contraction of the muscular fibres of the ventricles, and the striking of the apex of the heart against the wall of the chest; to a certain extent, the opening of the semilunar valves, and the rush of the blood into the pulmonary artery and aorta contribute to it. The second sound is due to the shutting of the semilunar valves of the aorta and pulmonary artery.

Sounds of the heart.

At each contraction of the ventricles the heart strikes against the walls of the chest, usually between the fifth and sixth ribs, and an inch or two to the left of the sternum. This motion is partly due to the action of the spiral muscular fibres of the ventricles, which gives a tilt to the heart, and partly to the globular form which the whole organ suddenly assumes.

The number of pulsations made by the heart differs very much at different periods of life: at birth it is from 130 to 140 per minute; at the seventh year, from 80 to 85; during mature life, from 70 to 75; and in old age, from 50 to 65. In females it is more frequent than in males. It observes a general relation with the number of respirations, five pulsations commonly occurring during one respiration. It varies with incidental circumstances. During sleep it declines in frequency; after eating, or during exercise, it is quickened. Examined from morning to evening, it becomes slower by degrees. Lying down, the pulse is slower; in a sitting posture, more frequent; and still more so when standing, the variations depending on muscular exertion. In conditions of disease, the ratio between the number of pulsations and respirations is variable.

Number of pulsations.

The walls of the left ventricle are twice as thick as those of the right, and the force of its contractions is about double. The capacity of the two ventricles is nearly the same, and is taken at about three ounces. The active force with which the auricles dilate is feeble, and wholly incompetent to exert any thing like the suction power at one time supposed, yet that they are not distended by the mere influx of the blood is satisfactorily proved by their dilatation after the heart has been cut out.

Structure and power of the walls.

With respect to the absolute force which the left ventricle exerts for the propulsion of the blood into the systemic arteries, it is stated to be 13 lbs. This result is derived from the consideration that the pressure of the blood in the aorta is about 4 lbs. 3 oz.

That the motions of the heart can not be referred to the presence of the

Cause of the motions of the heart.

blood, or any reflex action arising from the cerebro-spinal system, but must be attributed to the organ itself, is proved by their continuance after its excision from the body, or even after it has been cut in pieces. Some have supposed that the minute sympathetic ganglia with which it is furnished are the source of the motive power; others are disposed to impute it to a self-contractile power of its muscular fibres, irrespective of any nervous agency. Of course, it is admitted by all that the brain and spinal cord can influence these movements, but such effects are superadded and not uniform.

Of these opinions, we shall find many reasons for preferring the first when we come to the description of the nervous mechanism. It will be then seen that one of the prominent functions of nervous ganglia of a certain order, and particularly the ganglia of the sympathetic, is the storing up of impressions they have received, and thus becoming reservoirs or magazines of force. The power thus engendered or contained in them is by no means always delivered out in totality at once, but it may be in small portions, at intervals, for a long time; and doubtless in this way the minute sympathetic ganglia of the substance of the heart retain a power of keeping up the motions of that organ for a certain period of time, even though great lesions or morbid changes may have supervened. Such a mechanism recalls the manner in which chronometers are kept going during the short time that the action of the main-spring is taken off when the watch is wound up.

Description of the arteries.

2d. The arteries are tubes consisting of different tunics or layers variously numbered by anatomists, but which may be sufficiently described as, 1st. The exterior tunic, containing fibres generally running lengthwise, connective and elastic tissue: it is of about the same thickness as the tunic below; 2d. The middle tunic, characterized by being composed of non-striated muscular fibres circularly arranged; 3d. The interior tunic, which is thin, and consists of a cellular or epithelial layer, smooth and polished, to permit of the ready passage of the blood.

The elasticity of the arteries enables them to sustain the sudden action of the heart by distending to a certain degree as the blood is driven into them, and by their gradual collapse when the ventricles cease their pressure, the jetting or intermitting flow is converted eventually into a continuous stream. The mechanical influence of the heart is thus decomposed into two portions: one, which is of momentary duration, or, at all events, lasting only so long as the ventricle contracts; and a second, which is occupied in distending the elastic arterial tube; but this portion is not lost to the circulation, since the tube, as it contracts, yields it back again to the blood. The momentary impulse of the heart is thus spread over a considerable duration without loss.

The muscularity of the arteries is shown by their contraction on exposure, their subsequent dilatation being due to their elasticity, this contractile property being continued for some time after death. It is also proved by the great diminution of diameter which arteries exhibit when under the influence of an electric current. The quantity of muscular and elastic tissue in different arterial tubes is usually in an inverse proportion. In the great arteries the elastic tissue abounds, in the smaller the muscular increases. By their muscular coat the quantity of blood in these tubes can, within certain limits, be regulated.

Action of the arteries.

At each injection of blood into it an artery distends. It then contracts, and thus gives origin to a pulsation. Its increase is both in diameter and length, the tendency being to lift it at each pulsation. The distention does not occur at the same instant in all these tubes, but those nearest to the heart yield first, and the more distant a little later. There is therefore what may be termed a wave of distention passing throughout the length of each arterial tube, and another actual wave in the blood itself. These pass onward at different rates of speed. The interval of wave-motion from the heart to the wrist is about one seventh of a second. Of course this wave-motion is to be distinguished from the absolute movement of the blood, which is much slower. In the carotid artery the flow of the blood is about one foot in one second.

A pressure or impact, communicated to a liquid in a long tube, is transmitted to the more distant end with vastly more rapidity than the liquid itself could flow through the same distance. Thus, if we were to suppose a very long metal tube to be filled completely with water, its two ends having been tightly closed by tying pieces of bladder over them, the tap of a finger on one of the pieces of bladder would be almost instantly felt by a finger laid on the other. Indeed, it has been proposed to establish telegraphic communication on this principle, though such attempts would prove abortive from the interference of collateral circumstances. This example may serve, however, to illustrate the essential difference between the flow of a liquid in a tube and the passage of a pulsation through such a liquid contained in such a tube.

The capillaries.

The capillaries may be regarded as tubular continuations of the arteries and the commencement of the veins. They ramify through the organic structures. They are of pretty uniform diameter, and may therefore be looked upon as cylinders. Their usual size is about $\frac{1}{3000}$ of an inch; their mode of distribution varies with the structure and functions of the part they occur in: thus, in muscles they run parallel; in the papillæ they are looped.

They consist essentially of a delicate structureless membrane, analogous to cell membrane, and the sarcolemma of voluntary muscles. It

possesses a certain degree of elasticity, and presents here and there cell nuclei.

Fig. 61.

Capillary distribution to mucous membrane of stomach.

Fig. 62.

Capillary distribution to villi of duodenum.

Size of interspaces. The interspaces between adjacent capillaries vary much in size and shape, the latter variation being dependent on the mode of distribution, whether parallel, reticulated, looped, &c.; as to size, in the liver the interspaces are of less diameter than the capillaries, in the choroid coat still smaller, but in the cellular coat of the arteries they are ten times larger than the vessels. These interstitial spaces are nourished by the matter which exudes through the thin walls of the capillaries.

Fig. 63.

Capillary circulation of frog's foot.

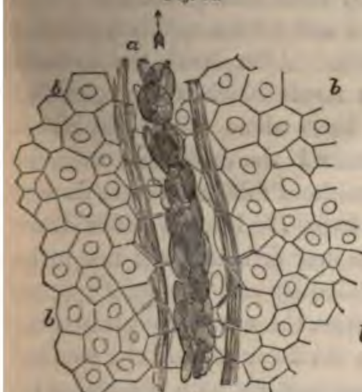
Fig. 63 represents the capillary circulation in the web of the frog's foot: *a*, venous trunk; *b*, *b*, branches of venous trunk; *c*, *c*, pigment cells. The elliptical blood-discs are seen in outline in the interior of the vessels.

The blood flows through the capillaries in an uninterrupted stream, its jetting motion being entirely lost. The rate of circulation through the systemic capillaries is

Motion of the blood in the capillaries.

aken at three inches per minute, that through the pulmonary being five times as quick, the length of the capillary tube to be passed $\frac{1}{80}$ of an inch, so that the passage from the artery to the vein may be accomplished in less than one second. It is to be remarked, however, that all parts of the cylindrical stream do not move with equal rapidity. Those parts which are nearest to the wall of the vessel are spoken of as the still layer, from their tardy movement. It is in this that the white corpuscles may be seen.

Fig. 64.



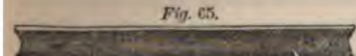
White corpuscles in the still layer.

Fig. 64 shows a portion of a small vessel from a frog's foot: *a*, *a*, red blood elliptic cells, occupying the axis of the vessel, and exterior to them, moving more slowly, or occupying the still layer, the white spherical cells; *b*, *b*, nucleated epithelium.

The veins: their structure.

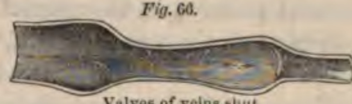
4th. The veins have a structure in some respects different from that of the arteries. Their elastic coat is by no means so much developed, and their muscularity less distinct. With the exception of those of the lungs, abdominal viscera, and brain, their interior is furnished with valves of single, double, or triple flaps, in all instances opening toward the heart. The blood flows equably in them, the pulsating action of the ventricles having disappeared in the capillaries. Since they present an aggregate capacity two or three times that of the arteries, the motion of the circulation in them is proportionally slower. *Fig.* 65 is a diagram showing the manner in which the valves open when the blood flows in the course indicated by the arrows.

Fig. 65.



Valves of veins open.

Fig. 66.



Valves of veins shut.

Fig. 66 shows their application to each other, or to the sides of the vein, and the consequent bulging of that vessel when the current, as indicated by the arrows, is in the opposite direction.

Having now described the structure and action of the heart, the arteries, capillaries, and veins respectively, as far as is necessary, it remains to group those actions together, and present the theory of the circulation at one view.

Error of the doctrine that the heart is the sole cause of the circulation.

But, before entering on this, it is proper to offer an argument against the doctrine of those physiologists who still maintain that the circulation is wholly dependent on the heart, and that that organ is entirely competent to carry it on.

The majority of the circulations we examine in organic forms are accomplished without any heart. Plants have none; fishes have no systemic heart; even in man, at the first period of embryonic existence, there is no such central organ; in his adult condition the portal circulation has none. The current of blood in the capillaries, seen under the microscope, exhibits no jetting movements, but, on the contrary, a steadiness of flow, sometimes for long in one channel, then a cessation, then perhaps a retrogradation, and then a new path. It looks as though the blood was flowing spontaneously, and not by any force acting behind. The heart of an animal may be suddenly cut out, and yet the capillary motion may go on in the same direction as before. After death the arterial tubes are most commonly found empty: a result which is a mechanical impossibility on the supposition that the heart alone drives the blood, but which ensues as a necessary consequence if the capillaries draw it. In acardiac monsters the blood circulates without difficulty, and, though it was at one time supposed that in these twins the hearted fœtus drove the blood through the heartless one, this is now demonstrated not to be the case. The circulation, moreover, varies locally, and at special epochs, as in the development of the generative organs, the mammary glands, the flow to the erectile tissues. Ubi irritatio ibi fluxus is an old medical aphorism, and these local variations are incompatible with the action of one central unvarying force. In cases of spontaneous gangrene, it sometimes occurs that the circulation through the part has declined, while the capillaries are all open, as subsequent examination proves. The application of cold to a part checks the circulation through it, and this not through any contraction of the vessels; so, likewise, does a jet of carbonic acid gas directed upon them. Moreover, any retardation in the supply of air to the lungs restrains the circulation, and this not alone in the pulmonary vessels, but also in the systemic capillaries, producing an increased pressure in the arterial tubes, a diminished one simultaneously occurring in the veins; and if, in the various cases now mentioned, the propulsive action of the ventricles can not be relied on to explain the difficulties, neither can any supposed suction or exhausting action of the auricles. When a ligature is tied round a vein, the action of the auricle is cut off, but the vein distends beyond the obstruction, showing that there is a force acting from the capillaries. Flexible tubes, such as are those vessels, would at once collapse under the exertion of a very moderate suction power, far less in intensity than would be necessary to draw the blood in the veins.

In spasmodic asthma, and in all pulmonary congestions, the right side of the heart circulates the blood with difficulty through the lungs, showing the existence of a great obstruction to its motion through the pulmonary capillaries. An examination of the condition of the various por-

tions of the circulatory apparatus after death presents facts utterly inexplicable on the doctrine of the sufficiency of the heart. I have already mentioned the empty state of the systemic arteries; to this may be added what is often witnessed—the distended condition of the pulmonary artery, into which the blood has been forced by the expiring beats of the right ventricle, but has been unable to get through the pulmonary capillaries because of the cessation of respiration; but in other cases, where respiration has come to an end more tranquilly or slowly, the left auricle is full of blood, which must have been driven into it by the pulmonary capillaries. In sudden death, as by hanging and drowning, the right heart is excessively distended, as is also the pulmonary artery.

I might proceed to add to these other facts exhibiting local variations of the supply of blood in the periodicities of the system. There is a certain amount sent to the brain during the day, and a less during the repose of the night; in the muscular system, during the time of its action, the quantity demanded is greater; in its state of inactivity, less. A constant and invariable acting machine, such as is the heart, could by no possibility adjust these variable supplies. But the cases here offered are more than enough, and it remains to be added that, though not one of them can be explained on the doctrine of the sufficiency of the heart, there is not one which does not follow as a necessary consequence of the doctrine now to be presented.

On this view, the circulation is conducted in the following manner: The left ventricle of the heart impels the blood into all the aortic branches, any backward regurgitation into the auricle being prevented by the shutting of the mitral valve; the force employed is decomposed into two portions, one part exerting an instantaneous effect on the blood in pressing it forward, and ceasing instantaneously, and thus giving origin to the pulse; the second distending the arterial tubes, but not being lost thereby, since their elasticity causes them to contract, and the semilunar valves at the origin of the aorta being at this period shut, a steady, onward pressure is exerted on the blood; so the quickly-ending action of the ventricle gives origin to two distinct mechanical results—a sudden impact and a continuous pressure. This suffices to bring the blood to the arterial origin of the capillaries, and beyond that point the action of the heart may be considered not to extend.

Explanation of the circulation of the blood.

The relation between the interspaces of the capillaries and the blood thus introduced to them continues the current. The particular mode in which this relation is manifested differs in different parts. The oxidizing arterial blood has a high affinity for those portions that have become wasted: it effects their disintegration, and then its affinity is lost. The various tissues require repair; they have an affinity for one or other of

the constituents of the blood; they take the material they need and their affinity is satisfied; or secreting cells originate a drain upon the blood, and the moment they have removed from it the substance to be secreted, they have no longer any relation with it. So processes of oxidation, and processes of nutrition, and processes of secretion, all conspire to draw the current onward from the arteries, and to push it out toward the veins; and though these processes may present themselves in many various aspects, they are all modifications of the same simple physical principle.

The blood has now reached the veins, and is forced onward in them by the power that has thus originated in the capillaries. The influence of the heart is here unfelt, the exhausting action of its right auricle is unappreciable, and, thus pushed onward from the capillaries, it reaches the heart, completing its systemic or greater circulation. This circulation may therefore be said to be due to the high affinity which arterial blood has for the tissues, venous blood having none; and the action of the heart is confined to the filling of the arterial tubes, and presenting fresh portions of blood to the capillaries.

Arrived at the right auricle, the blood flows continuously into it and the right ventricle for a moment, but the ventricle holding more than the auricle, the latter cavity is fully distended first. At that instant it contracts, the valves in the veins shutting, and the blood, driven thus forcibly into the ventricle, distends it to the utmost. The ventricle, in its turn, now contracts, the tricuspid valve shutting, and the blood issues forth through the pulmonary artery, its valves then closing. At this moment an event occurs which, in these descriptions, is generally overlooked—an action analogous to that of the hydraulic ram. On the shutting of the tricuspid, the whole column of venous blood would be brought to a stop if the tubes containing it were unyielding, and a great force would be generated from this stopping of its momentum; but the auricle is ready to dilate, and into its cavity the blood, which would be otherwise checked, flows. I consider that this safety action of the auricle is one of its prime functions. The rapidity with which the dilatations and contractions are taking place furnish no argument against the occurrence of this action. I have a hydraulic ram, the pulsations of which may be so adjusted as to exceed greatly in frequency those of the heart, and, indeed, to give rise to a low murmuring sound, and yet, under these circumstances, the lateral force is so great as to throw a column of water more than forty feet high. If it were not for the dilatability of the auricles and their yielding texture, the veins would burst on the shutting of the tricuspid valve.

The ramifications of the pulmonary artery bring the blood to the capillaries of the lungs, but beyond that the influence of the heart is not felt, for now the physical principle heretofore described comes again into action. The venous blood has a high affinity for the oxygen of the air, an

affinity which is satisfied as soon as the blood presents itself in the cells of the lungs. Arterialization being accomplished, the portions to be changed exert a pressure on those that have changed, and the blood, moving forward in the pulmonary veins, reaches the left auricle of the heart.

For a moment it passes into the left auricle and ventricle continuously, but the auricle, being of less capacity, fills first. It contracts as soon as it is completely full, and drives its contents into the left ventricle, distending it to the utmost. The ventricle now contracts, shutting the mitral valve, and the ram-like action is repeated on this side of the heart. But the blood expelled from the ventricle is urged into the aorta, its force being decomposed, as before described, one part acting instantaneously as an impact on the blood, the other on the arterial walls, and on the first moment of the recession of the walls of the ventricle the semilunar valves of the aorta shut, and this act completes one tour of the circulation of the blood.

In this description I have said nothing of the circulation in the substance of the heart itself, since it would have led to a needless complication. It should be remembered, as an illustration of the working of the physical principle here explained, that the motion of the blood is contrary in the greater and less circulations, compared together. In the former, the current is from the crimson to the blue, in the latter, from the blue to the crimson side.

Correct statement of the heart's action.

The action of the heart is therefore limited to the filling of the arterial tubes, so as to present to the capillaries a constant supply of blood. There seems to be but little suction force exerted by the auricular cavities for the emptying of the veins. The valvular construction of these vessels economizes every pressure that the muscles may exert on them in favor of the circulation, for every such pressure must, by reason of the valves, force the blood onward to the heart. This is, however, only an incidental result of the same character as the influence which the motions of respiration exert. They may be properly overlooked in a general statement of the causes of the circulation.

Various facts supporting this explanation.

By regarding the affinity between the blood and the tissues with which it is in contact as the great primary cause of the circulation, we assign a reason for those various phenomena which can not be accounted for on Harvey's doctrine: the motions in the embryo; the periodic and local variations; the portal circulation; the changes in the current, as seen under the microscope; the movement in the capillaries after the heart is cut out; the empty condition of the arteries after death; the phenomena of acardiac fœtuses; local inflammations and congestions; the gangrene of parts while their capillaries are pervious; the retardation of the current on the application of cold or of carbonic acid gas; the results of asphyxia and death by drowning or

hanging; the changes of pressure in the arteries and veins respectively during a check on the respiration; the vis a tergo of the veins; the effects of a ligature on those vessels; the action of irrespirable gases when breathed, and the opposite conditions when oxygen gas or protoxide of nitrogen are used.

The first breath.

Among the striking proofs of the truth of this doctrine, that the primary cause of the circulation is the aeration of the blood, I would particularly direct attention to the effects which ensue in the moment of birth at the first breath. That intercommunication between the two sides of the heart, established through the foramen ovale and through the ductus arteriosus, is suddenly put an end to. But this is not through any change in the mechanism of the heart itself, nor because of any interruption in the action of the placenta. It is solely because of the calling into operation of the principle we have been here enforcing. Through the contact of the cold air, or other causes which might be assigned, the inspiratory muscles make their first contraction and distend the lungs. At that instant, the commencing arterialization produces a pressure, in the manner I have explained, of the venous upon the now arterialized blood in the vessels of the pulmonary cells. There is no other possible issue to such an action than an instant drain upon the heart. The pulmonary or less circulation sets in with full vigor. The blood is not driven by the heart to the lungs, but drained by the lungs from the heart. If it were the heart's action that occasioned this sudden increase of force, because of the strain thrown upon it through the shutting off of the influence of the placenta, it is inconceivable why the current should not continue to move through the great avenues already open to it from the right to the left auricle through the foramen ovale, and from the right ventricle into the aorta through the ductus arteriosus. The arrest of its motion through these channels distinctly establishes that the seat of the new action is in the lungs, and the final closure of the foramen and shriveling of the duct confirm the correctness of this conclusion.

Though it does not strictly belong to the subject now under consideration, I can not avoid impressing on the reader the suddenness of the effect that thus ensues on the taking of the first breath. It is a crisis in the history of development. Of these changes by crisis much more will be said in the second book, and their important bearings on the theory of physiology pointed out. It is enough for the present purpose to commend to the attention of those naturalists who deny that physiological crises ever occur, the facts which have been considered in the preceding paragraph.

A doctrine which accounts with simplicity for such a long list of miscellaneous facts commends itself to our attention at once. There are,

however, considerations of a still weightier character, which must compel us to adopt it. The affinity between the blood and the parts with which it is brought in contact is a chemical fact beyond contradiction. The pressures and motions I have been speaking of follow as the inevitable consequences of that affinity. We can not, therefore, gainsay their existence in the living mechanism, and the only doubt we can entertain is as to whether they are of competent power to produce all the effects before us. But after what has been already said respecting the energy of endosmotic movements displayed against pressures of many atmospheres, we may abandon those doubts; and since we have here a force of universality enough, and intensity enough, and in every instance acting in the right direction, it would be unphilosophical to look farther, since such a force *must*, under these conditions, exist in the physical necessity of the case.

CHAPTER IX.

OF RESPIRATION.

Respiration introduces and removes aerial Substances.—Coalescence of Respiratory and Urinary Organs in Fishes.—Physical and chemical Conditions of Respiration.—Interstitial Movements of Solids, Liquids, and Gases.—Condition of Equilibrium in the Diffusion of Gases.—Condensing Action of Membranes.—Forms of Respiratory Mechanism.—The Lungs of Man.—Three Stages in the Introduction of Air: Atmospheric Pressure, Diffusion of Gases, and Condensation by Membranes.—Exchange of Carbonic Acid for Oxygen.—Divisions of the Contents of the Lungs.—Variations in the expired Air.—Removal of Water.—Effect of irrespirable Gases.—Experiments of Regnault and Reiset.—Nervous Influence concerned in Respiration.—Results of Respiration.

SINCE it is essentially necessary to the life of all animals that the blood should pass to every part of the system, provision must be made for securing aeration. The breathing apparatus is the skin, or some extension, reflection, or modification of it.

Objects of respiration.

Besides the great duty of originating the circulation, respiration is connected with others of equal importance. The functional activity of the nervous and muscular tissues is dependent on their oxidation, and this implies the introduction of air. In each tribe, moreover, it is necessary to keep the temperature up to a specific point. This also is accomplished by oxidation, either of the disintegrating material which is passing to waste, or of combustible substances, such as sugar or fat.

All organic material, at its death, eventually gives origin, under the action of the air, to two products with which the function of respiration is mainly concerned. These products are carbonic acid and water. With the exception of gelatin, the other

Final products of tissue metamorphosis.

respiratory elements of food—fat, sugar, starch, &c., yield these two products alone. The nutritive elements give rise to nitrogenized compounds in addition. The conditions of life are such that carbonic acid can not be permitted to accumulate in the system, and means have therefore to be resorted to for its removal. The introduction of oxygen and excretion of carbonic acid are accomplished by the same mechanism, the lungs, the action of which is dependent on a physical principle.

Respiration is connected with aerial and vaporous matter only.

Under its simplest condition, respiration consists in the passing of carbonic acid with the vapor of water from the system, and the reception of oxygen in exchange. The construction of the apparatus which accomplishes this double duty in atmospheric animals is such that it can deal with substances in the aerial state alone. Nothing can be introduced through the lungs or escape therefrom except it be in the gaseous or vaporous form. All those products of disorganization which are not presented under this condition must therefore be removed by other organs, and this is more particularly done by the kidneys.

Coalescence of the respiratory and urinary organs in fishes.

But in aquatic animals, as in fishes generally, there is not this restriction or concentration of function, for the gill, being in contact with water, offers a channel for the passing away of many products of waste which, from their non-aerial state, could never escape through a lung, and so I regard this organ, the gill, as in a measure sharing the duty of a kidney in eliminating nitrogenized and perhaps saline matters. Comparative anatomists have long recognized that the so-called kidney in fishes approaches in character the Wolffian bodies largely developed in the fœtal condition of man. I am disposed to believe that the physical interpretation of this depends on the fact now before us, and that the gill in fishes, and the placenta, in part, in mammals, discharge at once the double office of a respiratory and urinary organ. It is consistent with the scheme of organic design that there should be this separation and concentration of function as development takes place.

These considerations would therefore lead us to expect that we should find in the respiration of air-breathing animals that function in its purest and least complicated form, and this is accordingly the case. If it be merely the skin that is relied on, as in the low orders of aerial life, or if the mechanism be constructed on the type of carrying the air to the blood, as in insects, or that of carrying the blood to the air, as in man, the operation consists essentially in the escape of carbonic acid and steam, and the reception of oxygen in return.

Respiration, like circulation, furnishes us with a signal instance of the employment of purely physical principles for the accomplishment of physiological purposes. It is with the pressure of the atmosphere, the

diffusion of gases, and the condensing action of membranes, that we have now to deal. These give us so precise and perspicuous an explanation of the act of breathing that it is needless to look beyond them; yet on that act depend the highest operations of life. In this particular the Scriptures have summed up the deductions of modern physiology in a single line—no metaphorical expression, but the simple assertion of a truth: He "breathed into his nostrils the breath of life, and man became a living soul."

Physical principles alone resorted to in constructing the respiratory engine.

Of the physical principles now to be dealt with, it is unnecessary to say any thing respecting the pressure of the atmosphere, since that is well understood; but not so with the phenomena of the diffusion of gases, and the condensing action of membranes. Though these are subjects which have been particularly examined by American physicians, the facts they have elicited are little known abroad. For example, the error of Valentin's statement respecting the diffusion exchanges of carbonic acid and oxygen, and the uselessness of the elaborate discussions which have originated therefrom, would at once have been recognized, had attention been directed to the facts developed here almost twenty years ago.

Interstitial motions are exhibited by solids, liquids, and gases. I have had occasion to examine Roman silver coins, from the interior of which the copper originally present had made its way out to the surface, forming the greenish incrustation known as patina by antiquarians, the silver being left almost pure. In speaking of absorption by the blood-vessels in Chapter VI., we had occasion to dwell upon the same propensity as shown by liquids, the endosmosis of Dutrochet being an example of it. The ready mobility of this group of bodies, arising from their diminished cohesion, greatly promotes these effects. Mr. Boyle collected a number of cases of solid movements in his tract on the languid motions of bodies.

Interstitial movements of solids and liquids.

Gases and vapors, by reason of their total want of cohesion, present the most striking examples of these effects. Their propensity to intermingle with each other is manifested, even though they be obliged to pass through crevices or winding passages. One of the first instances to which attention was directed occurred under the observation of Dr. Priestley, who found, on passing steam through an earthen tube placed in a furnace, that air would be delivered at the farther end. For some time he supposed that this experiment demonstrated the conversion of water into air by a great heat, but eventually traced it to its proper cause—the escape of the steam outward through the pores of the earthen tube, and the intrusion in the opposite direction of air from the furnace. This singular experiment may be well shown by attempting to pass steam through a red-hot tobacco-pipe, the

Priestley's observation on the endosmose of gases.

end of which dips beneath some water. A torrent of gas bubbles will escape.

Dalton's experiment on the diffusion of gases.

Mr. Dalton demonstrated that if a light gas be placed above a heavy gas in a suitable apparatus, the former, notwithstanding its levity, will descend, and the latter, notwithstanding its weight, will rise, and a complete and uniform intermixture will result. By such experiments he was led to believe that gases act as vacua to one another, and correctly explained the uniform composition of the atmosphere on this property of diffusion, or tendency of its constituents to intermix.

Fig. 67.

Diffusion of gases.

Thus, if a vial filled with hydrogen be placed with its mouth downward over the mouth of a vial of the same size containing carbonic acid gas, as shown at *h*, *c*, *Fig.* 67, in the course of a few moments the diffusion will be complete, and if the mixture in either vial be examined, it will be found to contain equal quantities of the gases.

Graham's experiments with stucco.

Professor Graham extended Dr. Priestley's observations on the passage through porous barriers. The substance he chiefly employed was a mass of dry plaster of Paris. This enabled him to prove that in the case of different gases diffusion takes place at different rates, which are dependent on the density of the gas. Perhaps the most satisfactory method of illustrating this class of results is by taking a porous earthenware cup, *a a*, *Fig.* 68, such as is used in Grove's voltaic battery, drying it perfectly, and cementing into its mouth an open glass tube, *b*, three quarters of an inch in diameter, and a foot or more long. A wide-mouthed bottle, *c c*, being placed as a temporary cover over the porous cup, it may be filled with hydrogen gas by displacement; and if the end of the glass tube be put into water contained in a reservoir, *d*, the water will rush up the moment the bottle is removed. When this motion is completed, if a jar of hydrogen be held over the porous cup, the water will be driven down with great rapidity, and a number of air-bubbles quickly escape. The extraordinary speed with which a gas will flow in and out of pores could not be better displayed. This rapidity of motion is an element with which the physiologist has to deal, as we shall presently find.

Diffusion through porous earthenware.

Fig. 68.

Diffusion through earthenware.

Diffusion through India-rubber.

Even when the texture of the substance is much closer, and the pores of extreme minuteness, similar results can be obtained, as was shown in the experiments of Dr. Mitchell, of Philadelphia, who employed thin sheets of India-rubber. If, over the mouth of

a glass bottle, such a thin tissue be tightly tied, and the bottle placed in an atmosphere of carbonic acid gas, movement at once takes place, a little air flowing out of the bottle into the carbonic acid, and so large a quantity of the acid passing the opposite way that the India-rubber soon swells outward, and eventually caps the bottle like a dome, as in *Fig.* 69, at *b*. Or, if the conditions be reversed, the bottle being filled with carbonic acid, and then exposed to the atmosphere, the India-rubber will be depressed, as at *a*, and stretch so as almost to sink to the bottom. Such experiments therefore prove that, even though barriers of a very close texture should intervene, gases will pass through them, and with so much force, as Dr. Mitchell showed, that many inches of mercury may be lifted, nor does the movement cease until the gases on both sides of the membrane have the same composition.

Fig. 69.

Diffusion through India-rubber.

Other substances having a close texture may be thus readily permeated. I found that a little bladder of shellac, blown on the end of a glass tube, permitted the passage of the vapor arising from water of ammonia. The instantaneousness of these motions is, however, most beautifully illustrated by employing soap-bubbles, the liquid nature of which excludes the idea of pores in the strict acceptation of that term. If a bottle, *a a*, *Fig.* 70, be rinsed out with ammonia, and then, by means of a piece of glass tube, *b b*, a soap-bubble, *c*, be blown therein, the air from the bubble being immediately drawn into the mouth without a moment's delay, the strong taste of the ammonia is perceived. Or if a rod, dipped in hydrochloric acid, be presented to the projecting end of the glass tube, copious white fumes arise. This therefore shows that vapors will pass through barriers having no proper pores, the transit taking place instantaneously.

Experiments with soap-bubbles and liquids.

Fig. 70.

Instantaneous passage of gases through films.

Soap films enable us to demonstrate the endosmosis of gases in a very advantageous manner, owing to their cohesiveness and thinness. If the finger be dipped in soap-water, and then rapidly passed over the mouth of an empty bottle, so as to leave a horizontal film attached across, on exposing the bottle to carbonic acid gas, the horizontality of the film is immediately disturbed, and it soon swells up into an almost spherical dome. Or if the bottle be filled with carbonic acid, and then exposed

to the air, the film is promptly depressed into a deep concavity, and bursts. By these methods the passage of all kinds of vapors and gases may be demonstrated, oxygen, hydrogen, carbonic acid, protoxide of nitrogen, the vapors of peppermint, lavender, and various essential oils.

By many experiments on such different substances, I found that the law of equilibrium for gases and vapors is the same as for liquids. No matter what the thickness or thinness of a porous barrier may be, movement takes place through it, until the media on its opposite sides have the same chemical composition. The observed action, in particular cases, will therefore altogether depend on the circumstances under which the experiment is made. A soap-bubble full of carbonic acid, exposed to the air in a closed bottle, collapses only to a certain extent, when the percentage constitution of the air it contains is the same as that of the air in the bottle, contaminated with the carbonic acid which the bubble has yielded it. But if the bubble be exposed to the free atmosphere, it collapses almost completely, for now the carbonic acid escapes finally away.

Law of equilibrium, and examples of it.

One of the most interesting facts connected with these results is the perfect manner in which a film of excessive tenuity will discharge these mechanical functions. With a little care, a film may be obtained so thin as to be invisible except in certain lights, when it presents a velvety black aspect. In this condition, as Newton has proved, it is not thicker than three eighths of a millionth of an inch, yet endosmosis takes place perfectly through it: it expands and collapses, rises up into a dome, or is depressed into a concavity, as the circumstances of its exposure may be. And this should prepare us to admit that in organic tissues of the utmost degree of tenuity these physical phenomena may occur, and that even under these most unlikely circumstances such tissues may give origin to mechanical forces of the greatest intensity, as we shall now prove.

Action through films of extreme tenuity.

Graham's law of the diffusion of gases has but a very limited physiological application. The introduction of it in cases to which it does not properly apply has led to several errors. There is nothing common in the result of the movement of gases exposed freely to one another, and exposed with the intervention of a close-pored tissue. The tissue itself gives origin to mechanical force of such intensity as not only to modify the diffusion rate, but, in a great many of the most important cases, absolutely to invert the direction of the motion. Thus, through a stucco plug, in which the pores are of sensible size, atmospheric air passes more rapidly to carbonic acid than carbonic acid does to it, but through the thinnest film of water just the reverse takes place. A bubble full of that acid, exposed to the air, lets it escape with so much rapidity that in a few moments a complete col-

Inapplicability of Graham's law.

lapse has occurred. If the law of diffusion here held good, the bubble should rapidly distend.

Condensing action of membranes.

Moist membranes and films of water, by reason of their chemical affinity for gaseous substances, and their consequent condensing action, become the origin of great mechanical power. Under such conditions, I have seen carbonic acid pass into atmospheric air, driven, as it were, by the action of the membrane against a pressure of ten atmospheres, and sulphureted hydrogen against a pressure of twenty-five atmospheres, and, even against these great resistances, the passage is accomplished with so much promptness as to lead to the inference that a membrane will cause one gas to diffuse into another, even though the apparent resistance be indefinitely great.

Fig. 71.

Great force of infiltration.

In *Fig.* 71 is given a representation of the arrangement by which these results were obtained. It consists of a strong glass tube, seven inches or more in length and half an inch in diameter, hermetically closed at one end, through which a pair of platina wires, *b*, *c*, pass into the interior of the tube parallel but not touching. The other end, *a a*, has a lip or rim turned on it. Between the platina wires, a gauge-tube, *d*, is dropped, to show the amount of condensation. On the top of the gauge-tube a small test-tube, *f*, is placed, to contain a reagent suited to the gas under trial, as lime-water for carbonic acid, acetate of lead for sulphureted hydrogen, litmus-water for sulphurous acid. Sometimes, instead of this test-tube, a piece of paper, soaked in the proper reagent, was employed. The large tube was then filled with water to the height *e e*. Its lip or rim, *a a*, being next smeared with burnt India-rubber, to insure absolute freedom from leakage, a thin sheet of India-rubber was tied tightly over it, and over this again, to give strength, a very stout piece of silk. Every thing being thus arranged, the projecting wires, *b*, *c*, were connected with a voltaic pile, decomposition of the water ensued, oxygen and hydrogen being disengaged, and a condensed mixture of atmospheric air and those gases accumulated in the space *a a e e*, the gauge-tube showing the extent to which the condensation had gone. Now if the little tube, *f*, had been filled previously with lime-water, and the whole arrangement was introduced into a jar of carbonic acid gas, the upper part of the lime-water presently became milky, and after a time a copious precipitate of carbonate of lime subsided. This would readily take place when the gauge was indicating a pressure of ten atmospheres. In like manner, when a piece of paper imbued with carbonate of lead had been introduced into the tube, and a pressure of 24¼ atmospheres accumulated, on introducing the instrument into a vessel of sulphureted hydrogen, the paper

Measure of the force of infiltration.

quickly became brown. So sulphureted hydrogen can pass through a sheet of India-rubber and diffuse into an atmosphere of oxygen, hydrogen, and atmospheric air beyond, though it is resisted by a pressure equal to that of 800 feet of water.

The method of condensation here employed, because of its freedom from mechanical concussions, enabled me to continue these researches up to pressures of 50 atmospheres without leakage, in comparatively slender tubes, and even under these circumstances gaseous diffusion seemed to take place without any restraint.

General facts connected with diffusion.

It would lead me too far from my present object to pursue the consideration of these facts, and I must therefore be content to refer the reader to the memoirs in which they have been specially discussed.* It is sufficient to understand, 1st. That gases simply exposed to each other inter-diffuse with great rapidity, and at a rate inversely proportioned to the square root of their densities; 2d. That the same takes place through stucco plugs, or diaphragms with open pores; 3d. That a gas dissolved in a liquid, or held in a condensed state by a solid mass, will exchange by inter-diffusion with any atmosphere to which it may be exposed, in these cases the liquid or the solid mass becoming a source of force; 4th. That through a liquid, which, of course, has no pores, gases arranged on its opposite sides will diffuse, but their rate is no longer expressed by Graham's law; 5th. That a liquid holding a gas in solution permits it to diffuse with another gas held by another liquid in solution.

On the first of these principles, the fresh air of the bronchial tubes exchanges with the respired air of the pulmonary cells, the case being that of a gas exposed to a gas. On the third of these principles, arterialization of the blood takes place, the case being that of a dissolved gas exchanging with a free gas; and on the fifth of these principles, aquatic or gill respiration depends, the case being that of a dissolved gas exchanging with another dissolved gas.

Various forms of respiratory mechanism.

Under its simplest aspect, the act of breathing consists in the elimination of carbonic acid from the system, and the introduction of oxygen. The manner in which the respiratory surface frees itself from the former, and secures new supplies of the latter, differs very greatly. In the lower orders which lead an aquatic life, currents are established in the water by the aid of ciliary motion, and by these the necessary changes are made. In others, in which respiration is conducted by the skin, incessant locomotion is relied on; and again, in others, the water is drawn into the stomach and intestinal canal, and every part bathed with the aerating medium.

In insects, the type of carrying air to the blood is developed to the ut-

* American Journal of Medical Sciences, May, 1838.

most degree, there being great numbers of tracheal tubes pervading all the soft parts. These occasionally present dilatations, acting as reservoirs—the foreshadowing of the respiratory cavities of the higher tribes. Of such, *Fig.* 72, representing the air-sacs or tracheal dilatations of the

Fig. 72.

Air-sacs of insects.

Fig. 73.

Spiracle of insect.

scolia hortorum, is an illustration. The tracheal tubes communicate with the external air through openings which may be obstructed by a valvular arrangement, as represented in *Fig.* 73. The photograph from which this figure was taken shows such a spiracle magnified 75 diameters. These organs may be seen arranged in rows on each side of the body; thus, in the common caterpillar, there are ten pairs. The mode of guarding the orifice varies in different cases, sometimes tufts of hair being resorted to, and sometimes, as in the figure, valves.

Respiration of insects.

The true lung is first recognized in the swimming bladder of fishes as a simple sac. In the carp, the tendency to a multi-chambered construction already appears under the form of two such bladders, *a*, *b*, communicating with each other through a narrow tube. These are connected with the œsophagus, *o*, by means of the pipe *c d*, the fish being thus enabled to

Fig. 74.

Air-sac of fish.

remove at pleasure a part of the air contained in the sacs by muscular compression. Though this mechanism is, as we have said, a rudimentary lung, it does not properly subserve the duty of such an organ, but is employed for producing variations in the specific gravity of the animal by compression or rarefaction of the included air. In these tribes the gills are the mechanism for aeration, which is ac-

Respiration of fishes.

complished in the following manner: The mouth is periodically filled with water, which is driven past the gills by muscular compression, and thereby the carbonic acid is removed from the blood which circulates in those organs, and oxygen is obtained in return. For this reason, a fish dies very quickly when its mouth is kept open. The angler knows that it is not owing to any loss of blood, nor to any injurious lesion that the hook may cause, but simply to suffocation, the water no longer lifting the gill covers, but merely passing out through the open mouth.

The experiments of Humboldt and Provençal clearly demonstrate the analogy between aquatic and aerial respirations; for water is not decomposed by the breathing of fishes: it is the air dissolved in it that is used. In the sample examined by these chemists, there was 20.3 per cent. of its volume of air, consisting of oxygen 29.8, nitrogen 66.2, and carbonic acid 4.0, in the hundred parts. After the fishes had remained in it for a due time, it still contained 17.6 per cent. of its volume of air, but this in 100 parts now consisted of oxygen 2.3, nitrogen 63.9, and carbonic acid 33.8. There had therefore been a consumption of oxygen and evolution of carbonic acid, together with a slight removal of nitrogen, this being the general result witnessed in aerial respiration. In a similar course of experiments on the breathing of gold fishes, made by myself, the result corresponds to the preceding statement, only the water I used was richer in oxygen gas, and the transposition into carbonic acid did not seem by any means to be so complete. I also remarked the same diminution in the quantity of nitrogen, but am disposed to attribute it not so much to the consumption of that gas by the fishes as to its diffusion from the water into the atmosphere, the solvent power having changed by the substitution of carbonic acid for oxygen.

Fig. 75.

Lung of reptile.

Respiration of reptiles.

In reptiles the lung presents the sac-like form, as in *Fig.* 75, a pulmonary artery passing on one side, and a pulmonary vein returning on the other: *a* is the trachea; *b*, its bifurcation; *c*, pulmonary artery; *d*, *d*, pulmonary vein. It often occurs that the two lungs are not equally developed, one of them, B, being rudimentary as compared with the other, A. Into such a sac in serpents the air is forced by muscular contraction, a kind of swallowing. It is expelled from them by the contraction of the abdominal muscles, and hence the hissing sound which it emits during its expulsion. From the simple sac to the cellular lung the advance is made by degrees, a development of parietal cells upon the inner surface taking place. At the intermediate stage, between the simple sac

and the highly subdivided respiratory organ of the mammals, the condition of things is well illustrated by the lungs of the frog. In *Fig.* 76, *a* is the hyoid apparatus; *b*, cartilaginous ring at the root of the lungs; *c*, the pulmonary vessels; and *d*, *d*, the pulmonary sacs.

Fig. 76.

Lungs of frog.

Respiration of birds.

Of all tribes, the respiratory mechanism is most highly developed in birds, which, besides being provided with lungs, have air-sacs between the muscles, and respiratory membranes spread on the interior of the hollow bones. It is in consequence of this that a bird is killed so readily, even by a very small shot, since it is scarcely possible to make a perforation into any part of the body without opening the respiratory cavity.

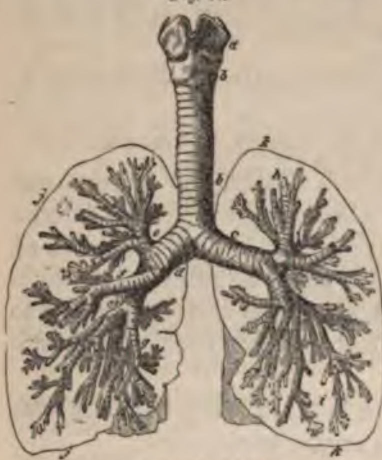
Lungs of man.

In man, the bronchial tube, as it passes into each lung, branches forth like a tree, the walls of the tubelets thus arising having cartilaginous rings to preserve their form under compression, circular organic muscular fibres to enable them to contract, and longitugitudinal fasces of elastic tissue to shorten them after extension. In their interior they are covered with mucous membrane provided with cilia. When the proper degree of minuteness, about $\frac{1}{50}$ of an inch, is reached, they consist alone of elastic membrane, interspersed with muscular fibres, and upon their sides the air-cells open; sometimes single ones, or sometimes many cells communicating with one another, discharge through the same orifice, the tubelet itself ending in a cell. The air-cells have various dimensions, from $\frac{1}{70}$ to $\frac{1}{1200}$ of an inch. Their structure is like that of the tubelet. The pulmonary capillaries are spread so closely upon them that the spaces between them are less than their own diameters, which, on an average, are $\frac{1}{3000}$ of an inch. As the cells are close together, the blood-vessels passing between them are brought in communication with the air on both sides, and arterialization is thus rapidly and completely performed. Each tubelet, with the air-cells thus clustered upon it, is a miniature representation of the lung of a reptile. These cells themselves communicate by lateral apertures with one another. The membrane which lines their interior is sharply folded at the apertures, and there are reasons for supposing that it contains organic muscular fibres. It is stated that each terminal bronchus has nearly 20,000 air-cells clustered upon it, and that the total number is 600 millions.

The mode of distribution of the air-tubes is represented in *Fig.* 77. *a* is the larynx; *b b*, the trachea, the upper letter corresponding to the

cricoid cartilage; *c*, the left bronchus; *d*, the right bronchus; *e*, *f*, *g*, its ramifications in the right lung, *j j*; *h*, *i*, ramifications of the left bronchus in the left lung, *k k*.

Fig. 77.



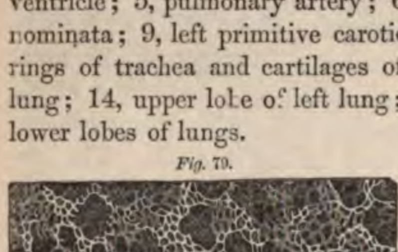
Human air-tubes.

Fig. 78.

The heart and lungs.

Fig. 78, arrangement of the heart and lungs, the latter in part section. 1, left auricle of the heart; 2, right auricle; 3, left ventricle; 4, right ventricle; 5, pulmonary artery; 6, aorta; 7, superior vena cava; 8, innominata; 9, left primitive carotid; 10, left subclavian,; 11, 12, upper rings of trachea and cartilages of the larynx; 13, upper lobe of right lung; 14, upper lobe of left lung; 15, right pulmonary artery; 16, 16, lower lobes of lungs.

Fig. 79.



Distribution of capillaries on air-cells of the lungs.

Fig. 79 illustrates the manner of distribution of blood-vessels on the air-cells of the lungs.

As the blood to be arterialized passes through the pulmonary capillaries, its discs can only move in single files, and even then probably undergo a compression which changes their form. As soon, however, as they escape into the larger vessels, their elasticity enables them to recover their original shape.

Three stages in the introduction of air.

By the aid of this elaborately constructed mechanism the air is brought to the blood. There are three distinct stages through which it has to pass. The first is the filling of the trachea and larger ramifications of the bronchial tubes: this is accomplished by atmospheric pressure, brought into play by muscular contrac-

The second stage is the translation of the fresh air from the larger hial tubes to the ultimate air-cells: this is accomplished on the ple of gaseous diffusion. The third stage is the passage from the lls into the blood: this is through the wall of the cell, the wall of lood-vessel, and the sac of the blood disc; it involves passage gh membranes, and implies their condensing action. Each of these stages we have now to consider.

. The introduction of fresh air into the trachea and larger ramifi- ns of the bronchial tubes is accomplished by muscular action, which calls into operation atmospheric pressure. nquil respiration the diaphragm is nearly sufficient for urpose. This muscle, forming the convex floor of the chest, as soon contracts, assumes more nearly a plane figure, thereby increasing ontent of that cavity; and, just as in a common bellows, when the board is depressed, the air flows in through the pipe, so, on the de- of the diaphragm, the air flows in through the trachea, forced by xternal pressure.

The effect of the pressure of the air.

Fig. 80.

chanism of respiration.

An experimental illustration of the manner in which the air is introduced into the cavity of the lungs by the descent of the floor of the chest, and then expelled by its elevation, is represented in *Fig.* 80, in which *a a* is a tube of glass half an inch or more in diameter, and six or eight inches long, to the lower end of which a bladder, *b*, is tightly attached. The tube is passed through the neck of a bell-jar, *c c*, air tight. A large glass reservoir of water, filled to the height *d d*, receives the bell-jar, as shown in the figure. When the jar is depressed in the water the air is expelled from the bladder, and when the jar is raised the air flows in. By alternately elevating and depressing the bell, the bladder executes movements like those of the lungs, of which, indeed, it is a representation; the glass tube being the trachea, the bell-jar the walls of the chest, and the rising and falling water-level the rising llling diaphragm. In this illustration the bladder is, of course, per- passive, as was at one time supposed to be the case with the lungs: roneous opinion, which will presently be corrected.

the mature period of life, and especially in deep respiration, the ac- f the diaphragm is insufficient for the introduction of air, still farther volume is obtained by raising the ribs, which ses the dimensions of the chest from right to left, and

Manner of introducing the air.

also from front to back. In men, this effect takes place more particularly through the movements of the lower ribs, and this form of respiration is therefore sometimes called the inferior-costal; but in women the upper ribs are more movable, the dilatation of the chest is there greater, and the respiration therefore designated as the superior-costal. In these movements of the ribs, and especially in violent respiration, many muscles are involved.

In the reverse act, that is, in expiration, or the expulsion of air through the trachea, the floor of the chest is raised. The diaphragm, when it contracted, made pressure upon the viscera of the abdomen, and forced the muscular walls of that cavity outward; but, as soon as the diaphragm relaxes, the abdominal muscles contract, and thus an antagonizing force is originated which tends to expel the air. In this the elasticity of the lungs and of the walls of the thorax itself affords a great assistance. Owing to this elasticity, the muscular exertion required for the introduction of the air greatly exceeds that required for its expulsion.

In tranquil respiration, we may regard the changing of the air to be accomplished by the alternate depression and elevation of the diaphragmatic floor of the chest. On an average, this takes place 17 times in a minute, and in an adult of the standard size we may assume that 17 cubic inches of air are introduced at each inspiration. Of every five breaths one is usually deeper than the other four. The statement often made, that five pulsations correspond to one respiration, must be received with a certain restriction. In pneumonia, the respirations may be to the pulsations as 1 to 2; in typhoid fevers, as 1 to 8; and even in a state of health there may be considerable variations.

By muscular movements, which thus call into action atmospheric pressure, the air is drawn, but not forced, into the respiratory apparatus. Considering, however, the solid contents of the lungs, which can not be taken at less than 200 cubic inches, it is clear that the amount is not more than sufficient to fill the nasal passages, the trachea, and the larger ramifications of the bronchial tubes. Lying nearest to the outlet, it would be the first to be expelled by the act of expiration. There could be no exchange of the fresh for the foul air, unless some additional means were employed for accomplishing its transference from the larger ramifications of the bronchial tubes to the remotest air-cells.

2d. The transference of fresh air to the cells is accomplished by resorting to two different principles, the diffusion of free gases into one another, and muscular contraction.

Effect of gaseous diffusion. Use of organic muscle fibres.

An estimate of the relative share which each of these takes is arrived at by an examination of the absolute velocity with which gases diffuse into one another. The statement that gases act as vacua to each other has led to some very erroneous

onclusions. It has been taken for granted that the actual diffusion is ery rapid, perhaps approaching to the velocity with which gases rush ito a void. But I have shown* that this is altogether a misconception, nd that the transit of fresh air from the bronchi, exchanging with foul ir from the cells, if conducted on that principle alone, would require a eriod greatly beyond the time occupied for one respiratory act, which is bout three seconds and a half.

To an additional agent we must therefore look for a complete explanaion, and this, I think, is presented in the circular organic fibres of the ronchial tubes and cells. It has long been understood that these posess the power of varying the capacity of the tubes.

With this agency in view, this second stage of the process is accomlished as follows: The carbonic acid, vapor of water, and excess of nirogen, if any, that have accumulated in the cells belonging to any given ronchial tree, are expelled therefrom by the muscular contraction of the ircular organic fibres, and are delivered into the larger bronchial tubes, n which diffusion at once takes place with the air just introduced. As oon as the expiration is completed, relaxation of the muscular fibres ocurs, and the passages and cells dilating, both through their own elasticty and the exhaustive effect arising from the simultaneous contraction of ther bronchial trees, fresh air is drawn into them, the alternate expulsion nd introduction being accomplished by muscular contraction and elasicity, the different bronchial trees coming into action at different periods f time, some being contracting while others are dilating.

Passage of oxygen through the membranes to the blood.

3d. The third stage is the passage of oxygen from the cells to the blood: t is through the wall of the cell, the wall of the blood-vessel, nd the sac of the blood disc. The carbonic acid issues from he plasma, and passes through the wall of the blood-vessel nd the wall of the cell.

Exchange of carbonic acid for oxygen.

Many physiologists have supposed that this exchange of oxygen for arbonic acid takes place on the principle of diffusion. On he authority of Valentin and Brunner, it has been asserted hat the proportional exchange actually observed is 1174 of xygen for 1000 of carbonic acid, these being the theoretical quantities nder the law of diffusion; but there is no difficulty in proving that this s a physical impossibility, for the exchange is not merely that of oxygen and carbonic acid; it is much more complicated. The lungs regulate the quantity of free nitrogen in the system, and there is a constant scape of the vapor of water. These bodies, moreover, are not presented in the gaseous state, but in that of liquid solution; and the wall of the cell, of the pulmonary capillary, and of the blood disc, by their condensing action, totally disturb the conditions of diffusion.

* American Journal of Med. Sciences, April, 1852.

If an aqueous film, not more than three eighths of a millionth of an inch in thickness, can completely disturb the law of diffusion by the condensing action it exerts on carbonic acid and oxygen, what may be expected from the moist walls of the air-cells and pulmonary artery, which conjointly must be more than a thousand times as thick?

From these complications, it is not possible to assign any definite ratio as expressing the gaseous exchange between the interior of the cells and the blood, for, so far from this being a case of exchange between two gases without any obstruction intervening, the condition under which alone the law of diffusion applies, the nitrogen is doubtless in a state of solution in the blood, the steam in the liquid condition of water; and respecting the carbonic acid, nothing certain is known whether it be in solution or chemically combined. Perhaps it is united with soda in the blood as a bi-carbonate. From this latter substance hydrogen gas will expel one half of its carbonic acid, and in like manner a stream of hydrogen gas passed through blood deprived of its fibrin removes carbonic acid. Upon such principles it has been supposed that atmospheric oxygen removes carbonic acid from the blood during respiration, just as would a stream of hydrogen remove half the acid from a solution of bi-carbonate of soda.

Place of the generation of carbonic acid.

The generation of carbonic acid in the system is commonly localized by referring it to the soft tissues. But, though doubtless much originates in this way, as is illustrated by the case of insects, in which the air is carried directly to the parenchyma of the organs without the intervention of any proper oxidizing blood, there can be no doubt that in man, as in all the higher tribes, a very large proportion is generated in the blood itself. If there were no other reason to bring us to this conclusion, it would be sufficient to recall that ultimate oxidation by no means occurs at once, but that the various wasted products pass from stage to stage in their retrograde career. Thus, between the syntonin of muscular fibre and the urea of the urine, many steps or stages intervene, and that much of these changes is accomplished in the blood itself is demonstrated by what occurs in the use of excesses of starch, albumen, or gelatine in the food. Such substances, finding access through the absorbents in a modified form, but not wanted for the repair of any part, are dismissed without ever entering into the composition of any organ, by the lungs or the kidneys as products of oxidation or derivatives thereof.

General statement of the process of respiration.

The act of respiration in man is therefore accomplished in the following way. The air, introduced by atmospheric pressure, brought into play by the action of the diaphragm and other respiratory muscles, fills the nasal passages, the trachea, and larger ramifications of the bronchial tubes. Between it and the gas

coming from the pulmonary vesicles, diffusion steadily takes place, tending to remove the cell gas into the atmosphere; but this gas is not brought from the vesicles by diffusion alone, which could not act with sufficient speed, but by the contraction of the circular organic muscles of the bronchial tubelets and of the cells, the different bronchial trees not acting simultaneously, but successively. As soon as contraction is over, the tubes expand by their elasticity, and the air is drawn into the cells, each bronchial tree, by its contraction, aiding the expansion of the adjacent ones. The lungs are therefore not altogether passive during respiration, as is sometimes said. The exchange between the gas in the cells and that in the blood does not take place through simple diffusion, or in quantities proportional to the diffusion volumes of oxygen and carbonic acid. It is a complex diffusion, in which the disturbances arise from the gases in the blood being either dissolved or combined, and through several intervening membranes, that of the air-cells, that of the pulmonary artery, and that of the blood disc, all of which exert a condensing action, of the result of which it is impossible to furnish any numerical estimate. The process ends by the expulsion of the foul air which has accumulated in the larger bronchi and trachea, by the diminution which takes place in the capacity of the chest during expiration, occasioned by the contraction of the expiratory muscles, the elasticity of the walls of the chest, and of the lungs themselves.

Such is the arrangement by which fresh air is constantly presented to the blood, and the gases and vapors exhaling from it are removed. The degree of exhaustion occurring in the chest scarcely justifies the expression sometimes used, "a tendency to a vacuum," since it is rarely more than competent to raise water a single inch. This may be readily proved by dipping a glass tube, open at both ends, and half an inch in diameter, into a cup of water, and placing the projecting extremity between the lips, taking care to keep the muscles of the mouth at complete rest. It will then be seen that at each inspiration the water rises about an inch, and at each expiration is depressed to a similar extent. Its movements indicate the degree of rarefaction or compression occurring in the chest.

Divisions of the gaseous content of the lungs.

It has been found convenient to consider the gaseous contents of the lungs under several different titles: 1st. The residual air is that portion which can not be removed by the most powerful expiration; 2d. The supplemental air remains after tranquil respiration, but can be removed at will; 3d. The breathing or tidal air is that portion which changes by tranquil inspiration and expiration; 4th. The complemental air is that which can be inhaled by the deepest inspiration, over and above that introduced by ordinary breathing. These are terms introduced by Mr. Jeffreys.

"The amount of air that can be expelled by the deepest expiration after the fullest inspiration" bears a singular relation to the height of the individual, as was discovered by Dr. Hutchinson. "For every inch of stature from five to six feet, eight additional cubic inches of air at 60° Fahr. may be thus given out." The quantity of air which can be thus expelled for the stature of five feet one inch is 174 cubic inches, and for six feet, 262. It is independent of the absolute capacity of the chest.

Connection between expiration and height.

The diurnal amount of air introduced into the lungs has been variously estimated from 226 to 399 cubic feet. A part, from 4 to 6 per cent., of the oxygen thus introduced disappears in the lungs, and the expired air is charged with from 3 to 5 per cent. of carbonic acid. But that nothing analogous to combustion occurs in those organs is proved by their temperature, which is not higher than that of other parts of the system. Moreover, carbonic acid can be withdrawn from venous blood in a Torricellian vacuum, and still better by agitating the blood with such gases as hydrogen and nitrogen, proving that that gas pre-exists in the venous blood before its entry into the lungs, and is not formed in those organs, unless, indeed, it exists as a bicarbonate, as already mentioned. The quantity of carbonic acid thus disengaged is less than the quantity of oxygen absorbed, because much of the latter is consumed in the production of sulphuric and phosphoric acids, which escape in the urinary secretion, as indeed does a large quantity of carbonic acid itself.

Volume and changes of the respired gas.

The experiments of Vierordt show that the expiration, in a state of rest, contains 4.334 per cent. of carbonic acid; that, as the number of respirations per minute increases, the percentage amount of carbonic acid diminishes; and that for every expiration, without reference to its duration, there is a constant amount of carbonic acid, namely, 2.5 per cent., to which we must add a second value, expressing the quantity of carbonic acid, and which is exactly proportional to the duration of the respiration, as is shown in the following table.

Vierordt's experiments.

Respirations per minute.	Percentage of carbonic acid.	Constants.	Augmentation of the percentage of the carbonic acid for the duration of the respiration.
6	5.7	2.5	3.2
12	4.1	2.5	1.6
24	3.3	2.5	0.8
48	2.9	2.5	0.4
96	2.7	2.5	0.2

Vierordt also estimates that, for the entire removal of the carbonic acid from the blood, more than three hundred respiratory acts per minute would be required. To some extent, the depth of the respiration will compensate for want of frequency. Thus he shows that in an expiration of double the usual volume, the quantity of carbonic acid removed is

nearly equal to that which would be exhaled by respirations of three times the normal frequency, and on examining a single respiration, he demonstrates what, however, would obviously be foreseen from a consideration of the circumstances of the case, that the last portions of the expiration are the richest in carbonic acid. Thus the first half of a respiration contained only 3.72 per cent. of carbonic acid, the last half 5.44 per cent.

Ratio of the inspired and expired oxygen.

With respect to the ratio between the quantity of oxygen inspired and that contained in the expired carbonic acid, a variation will be observed, depending on many conditions, as, for example, on the nature of the food. Thus, with a carbohydrate, the quantity of oxygen in the carbonic acid will always be less than that inspired, a portion being employed in the destruction of the systemic nitrogenized material which is undergoing decay. This destruction of nitrogenized material is not sufficient for the support of animal heat, and hence either carbohydrates introduced by the food, or fat already existing in the system, must be resorted to for the purpose of making up the deficiency. With such variations in the requirements of the system, and variations in the nature of the food, the ratio of the oxygen introduced to that in the carbonic acid removed must also vary.

For the perfect oxidation of the different elements of food, very different quantities of oxygen are required; thus, for the oxidation of 100 parts of fat, it would require 292.14 of oxygen; for that of starch, 118.52; for that of muscle, 147.04.

Variations in the respired air.

For reasons to be considered when we treat of the production of heat, the quantity of carbonic acid disengaged varies with external circumstances. When the weather is cold it is greater than when it is warm. Thus at 68° there is twice as much liberated as at 106°. It increases during exercise and after eating, but diminishes during sleep. More is set free by men than by women; it also varies with age, the proportion rising from eight years to thirty, remaining stationary to forty, and then declining. It changes with the frequency of the respirations. The total quantity of carbon daily removed by respiration may be estimated at eight ounces.

Water removed in respiration.

Besides the carbonic acid removed, a large quantity of water is excreted by the lungs, for the expired air may be regarded as saturated, or containing the maximum quantity of water for 94°. For the vaporization of this water much heat is consumed, as is likewise the case for the warming of the introduced air, which, no matter what the external temperature may have been, is brought to that of the lungs.

With respect to the absolute amount of air expired, and also the quantity of water removed by the lungs, some experiments have recently been

made by my son, Dr. J. C. Draper; the principle upon which they were conducted may be thus briefly stated. The air from the lungs, which has a dew-point of 94°, was passed by a wide tube through a metallic condenser kept at 32°, care being taken to have as little obstruction as possible to its egress. The weight of the water collected in the condenser furnished the means of calculating, by a simple formula, the quantity of air which had been expired, for the vapor, leaving the respiratory passages at 94°, and that leaving the condenser at 32°, were at their maximum densities. Computations executed upon data obtained on this principle furnish the following, among other interesting results:

Quantity of air expired per minute.

1. On making sixteen respirations in the minute, and continuing the experiment for twenty minutes, the average of five different series of experiments gives 622 cubic inches of air expired each minute.

2. On making six respirations in a minute, and continuing the trial for twenty minutes, the average of three series of experiments gives 511 cubic inches for the air expired each minute.

3. On making thirty-three respirations in a minute, and continuing the experiment for twenty minutes, the average amount of air is 1077 cubic inches for the air expired in each minute.

On comparing these three statements, it appears that, the first representing normal, the second very slow, the third very quick respiration, the absolute amount of air removed from the lungs is directly proportional to the number of respiratory acts in a given period of time, and this notwithstanding such variations in the depth of the inspirations as under such circumstances are likely to occur.

With respect to the quantity of water removed from the lungs, he also shows,

Quantity of water exhaled per minute.

4. That, at an atmospheric temperature of 55°, the dew-point being 49°, the number of expirations sixteen per minute, the quantity of water removed per minute is 4.416 grains.

5. The other conditions remaining the same, but the respirations reduced to six per minute, the amount of water removed per minute is 3.586 grains.

6. The other conditions remaining as before, but the number of respirations increased to thirty-three per minute, the amount of water removed per minute is 7.560 grains.

From these statements it therefore appears that the quantity of water removed from the blood by respiration increases with the frequency of the respiratory acts, and this notwithstanding variations which, under such circumstances, must take place in their depth. Theoretically, it is also obvious that the absolute amount thus expired is dependent on the existing dew-point of the air. In the general table, given on page 15,

the amount of water is calculated from Seguin's experiments, but it appears from these results, which are obtained by a much more accurate process, that the number there given is undoubtedly too high.

The time of exposure of the blood to the air is only a second or two. The color changes, as has been described before, from blue to crimson, and the temperature rises a degree or two, as is shown by an examination of the left cavities of the heart. The water thus removed is not pure, but contains animal matter in a state of decay.

Respiration is continuous and not reciprocating.

Though we have treated of the act of respiration as consisting of two separate and consecutive stages, inspiration and expiration, in reality it proceeds continuously. At the respiratory surface, which is the wall of the air-cell, the passage of oxygen inward, and of carbonic acid and steam outward, takes place in a steady and unvarying manner. The periodicity under which it has been convenient to speak of this function concerns only the introduction and removal of gases from the large air-ways.

Effect of respiration on the density of the blood.

Considering, therefore, the continuous loss of water which the venous blood brought by the pulmonary arterial branches undergoes, it must give rise necessarily to a greater density in the blood on the left side as compared with that of the right side of the heart. The total quantity of blood passing through the lungs in one minute is 225 ounces, and the loss of water from this in the same time can not be more than 7 grains. This, therefore, shows that the actual loss of water by the blood during its passage over the air-cells is about $\frac{1}{15000}$ part, a quantity which is altogether inappreciable, so far as its influence on the specific gravity is concerned, and showing us that the observations which some experimenters have made on this point, with a view of demonstrating an increased spissitude, density, or cohesiveness of the blood on the left side of the heart, from the giving up of its water as it passed through the respiratory organ, are either exaggerated or affected by some deceptive cause.

Effect of the introduction of irrespirable gases.

The introduction of an irrespirable gas into the lungs, or the prevention of the access of the atmosphere, brings the circulation of the blood to a stop; for that movement depends, as I have shown, on the aeration taking place in the pulmonary capillaries. In such cases there will be an engorgement of the right heart and vessels arising therefrom, but, if the stoppage has not lasted too long, the current may be re-established by re-establishing the respiration. Death commonly ensues on an exclusion of the air for five minutes, and, in cases of drowning, it is rare for restoration to be effected if the immersion has lasted more than four.

In the respiration of protoxide of nitrogen, a gas which is an energetic supporter of combustion, and acting more powerfully on the animal sys-

Effect of protoxide of nitrogen.

tem when respired than even oxygen itself, on account of its ready condensibility by pressure, or by membranes, and solubility in water, the circulation is greatly quickened at first, and a state of exhilaration ensues; but this is soon followed by a condition of depression, or even of coma, for the quantity of carbonic acid produced in the system is now so great that the lungs are wholly inadequate to effect its removal, and all the symptoms of poisoning by carbonic acid come on.

Zimmerman found that a rabbit exhaled $12\frac{1}{2}$ grains of carbonic acid per hour when breathing atmospheric air, but that the quantity rose at once to 20 grains per hour when it was caused to breathe protoxide of nitrogen. But by far the most complete and important series of experiments yet made in regard to the relations of the aerial medium and the respiring animal is that of MM. Regnault and Reiset, published in the Annales de Chimie, Juillet, 1849, of which, since it may be taken as a model of physiological investigation, a brief abstract is here given.

Summary of Regnault's and Reiset's experiments on respiration.

Fig. 81.

Experiments on respiration.

The apparatus they employed is represented in *Fig.* 81. It possesses the great advantage over all experimental arrangements heretofore employed in permitting an animal to be kept even for many days in a limited volume of air, but under such circumstances that that air was constantly kept at its normal composition by the automatic motions of the instrument itself: oxygen being thus furnished as it was required, and carbonic acid removed.

The arrangement consists of three parts: 1st, a chamber or bell, *l*, for inclosing the animal, surrounded by a jar filled with water, the temperature of which could be ascertained by a thermometer, *k*. In the interior of the bell was a platform perforated with holes, by the aid of which the excretions could be collected. On one side, at *p*, was a pressure gauge, connected with the bell by a tube, and showing the condition of condensation or rarefaction of the included atmosphere. 2d. At the same side, the bell communicated, by means of India-rubber tubes, *m*, *n*, with two cylindric vessels, *q*, *r*, filled with a solution of caustic potassa, and which were driven by the aid of powerful clock-work in such a way that the one alternately rose and the other descended, the flexible tube *s* permit-

ting this motion. The result of this was that a portion of the air of the bell was alternately drawn into each of the cylindric vessels, its carbonic acid removed by the potash, and then it was returned; so, as fast as the animal produced that gas by breathing, the potash removed it, giving rise, therefore, to a tendency to a certain amount of rarefaction in the air of the bell; but, 3d, on the opposite side of the bell were placed three receptacles, e, e', e'', filled with pure oxygen gas, which flowed into the bell through the tubes fh, $f'h$, $f''h$, to compensate for that rarefaction, coming in by a bubble at a time through the little potash flask i, the oxygen being pressed out of the reservoirs by a solution of chloride of calcium descending through a stop-cock, c, from a reservoir, b b', kept at a constant level in the usual manner by the flasks a, a', a''. As fast as one receptacle was exhausted, the pressure tube was successively connected with the others, and so the supply kept up. Attached to the stand supporting the animal was a eudiometer, o, which enabled a small quantity of air to be withdrawn from the bell at any moment for the purpose of analytical examination. For other details of this apparatus, and the particulars of its method of use, reference may be made to the original memoir itself. It is sufficient for the present purpose to understand that an animal could be kept in the interior of this bell for several days without showing any signs of discomfort, pure oxygen being supplied to it, and the carbonic acid produced by breathing removed by the play of the machine itself.

The following is an abstract of the results obtained:

Hot-blooded animals on an ordinary diet.

1st. Hot-blooded animals, mammalia and birds, under their ordinary diet, always disengage a little nitrogen by respiration, the amount varying from less than $\frac{1}{100}$ to $\frac{1}{50}$ of the weight of the oxygen they consume.

The same fasting.

2d. When these animals are fasting, they often absorb nitrogen in proportions similar to the preceding. In like manner, an absorption of nitrogen was observed after starving the animal, and then submitting him to a diet very different from his ordinary one, and also during sickness.

Influence of food and fasting.

3d. The ratio between the quantity of oxygen contained in the carbonic acid and the quantity consumed depends more on the nature of the food than on the class to which the animal belongs, being, when the animals are starving, the same as it is when they are fed upon meat, or perhaps a trifle less. From this the interesting conclusion may be drawn that a starving animal furnishes to the air of respiration his own substance, which is of course of the same nature as the flesh he eats when dieted on meat. All hot-blooded animals present, when they are starving, the respiration of carnivora. The ratio for the same animal varies from 0.62 to 1.04, according to the nature of the diet.

Respiration of birds.

4th. In fowls, submitted to their usual diet of grain, there is often more oxygen in the carbonic acid disengaged than was furnished in the air by respiration. The surplus of course comes from the food.

Influence of motion, age, health.

5th. The quantity of oxygen consumed in a given time varies with the state of digestion, motion, and other circumstances. Compared together, the consumption is greater among the young than among adults, greater among those that are lean but in good health than among those that are fat.

Influence of the size of animals.

6th. If we take an equal weight of the animals under examination, the quantity of oxygen varies much with their absolute size; thus it is ten times greater among little birds, such as sparrows and green-finches, than among common fowls. This is owing to the fact that, since these different species have the same temperature, and the little ones present relatively a greater surface to the ambient air, they must consume relatively more oxygen to keep up their heat to the standard degree.

Respiration of hibernating animals.

7th. Hibernating animals, such as marmots, when perfectly awake, exhibit no peculiarity, but when fast asleep often absorb nitrogen. The ratio of the oxygen contained in the carbonic acid to that inspired is very low, scarcely amounting to 0.4, the missing oxygen escaping in the compounds of the urinary secretion; but since this removal takes place only periodically, the sleeping marmot exhibits the remarkable phenomenon of increasing in weight by respiration alone.

8th. The consumption of oxygen by sleeping marmots is very small, scarcely $\frac{1}{30}$ of what they require when awake. At the moment they awaken from their lethargy, their respiration becomes extremely active, and during the period of their awakening they consume much more oxygen than when they are completely awake. Their temperature rises rapidly, and their members gradually lose their stiffened state. While torpid they can remain without difficulty in an atmosphere which would suffocate them in a few moments if awake.

Respiration of cold-blooded animals.

9th. Cold-blooded animals, for an equal weight, consume much less oxygen than hot-blooded. Frogs with their lungs cut out continue to breathe with nearly the same activity as before, often living for several days, the proportions of the gases absorbed and disengaged differing little from what is observed in the case of uninjured frogs. This shows that their respiration can be conducted by the skin. The respiration of earthworms is the same as that of frogs, as regards the quantity of oxygen consumed, when they are compared under an equal weight.

10th. The respiration of insects, such as May-bugs and silk-worms,

is much more active than that of reptiles. Under an equal weight they consume nearly as much oxygen as mammalia: the comparative lowness of their temperature is due to the relatively great surface and moist exterior they present to the air. It is to be remarked that we are here comparing the respiration of insects with that of mammalia whose weights may be from 2000 to 10,000 times as great.

Respiration of insects.

11th. The respiration of animals of different classes, in an air containing two or three times as much oxygen as the atmosphere, does not differ from existing respiration; indeed, the animals do not appear to perceive that they are in a medium different from the ordinary atmosphere.

Effect of increasing the amount of oxygen.

12th. The respiration of animals in a medium in which, for the most part, hydrogen replaces the nitrogen of our atmosphere, scarcely differs from existing respiration; only there is remarked a greater consumption of oxygen, due perhaps to the necessity of compensating for the increased cooling arising from the contact of hydrogen gas.

The introduction of air into the system is, to a certain extent, automatic, and, to a certain extent, dependent on the will. In tranquil respiration we are wholly unconscious of the motion; the exciting impression is made on the pneumogastric nerves, and, being conveyed to the respiratory ganglion, the medulla oblongata, is there so reflected that through the agency of the phrenic nerve motion takes place in the diaphragm. The automatic, and therefore unconscious movement, to a certain extent, occurs in that way. But there is no doubt that the brain also participates in the function. No other evidence of this is required than that we can "hold the breath," and the relative share that the voluntary and automatic mechanisms take is illustrated by the circumstance that this holding of the breath can only be persisted in for a certain time, when the necessity for respiring becomes altogether uncontrollable.

Nerves involved in respiration.

It is not, however, to be supposed that so important a condition as that of the introduction of the air is only slenderly provided for. Many other nerves, besides those mentioned, take part in it directly or indirectly; the fifth pair, the nerves of the general surface, and also the great sympathetic, the intercostals, the spinal accessory, which probably gives its motor property to the pneumogastric. Opinion has differed respecting the cause which produces the necessary impression on the receiving nerves, some referring it to the presence of venous blood in the capillaries of the lungs, and some to the carbonic acid in the cells. Moreover, there is reason to believe that the presence of an abnormal amount of venous blood in the respiratory ganglions will of itself give rise to respiratory movements through the proper centrifugal nerves.

The control possessed by the will over the introduction of air stands in a close relation to the production of articulate or other sounds, and therefore to intercommunication between individuals by speech. This involves not merely a general control alone, but also a particular one, which is reached by regulating the movements of the glottis by the agency of the superior and inferior laryngeal nerves. But though the will for these important purposes exercises so marked a power of regulation, it is to be looked upon as superadded or incidental, and during sleep, coma, and that larger portion of life which is spent in total inattention to the carrying on of this function, it is discharged in a purely automatic way.

Respiration partly voluntary and partly automatic.

The mechanism which accomplishes the surprising results of respiration may therefore well challenge our admiration. As a self-acting or automatic contrivance, over which we have not a necessary control, it originates in a single year nearly nine millions of separate motions of breathing. It never fatigues us; indeed, we are never conscious of its action. In the same time, a hundred thousand cubic feet of air have been introduced and expelled, and more than thirty-five hundred tons of blood have been aerated. In a future page we shall have to present the wonderful mechanism by which aerial currents, as they pass in and out of the respiratory apparatus, are incidentally employed as a means of producing musical notes or articulate sounds, and of thus establishing a relation and communication between different individuals. By these the feelings and thoughts are diffused, and in a mechanical origin commence those bonds which hold society together.

Results of respiration.

CHAPTER X.

OF ANIMAL HEAT.

Participation of Organic Forms in external Variations of Temperature.—Mechanism for counterbalancing these Variations.—Development of Heat in Plants at Germination and Inflorescence.—Its Cause is Oxidation.—Connection of Respiration and Heat.—Temperature of Man.—His Power of Resistance.—The diurnal Variations of Heat.—Connection of these Variations with organic Periodicities.—Annual Variations of Heat.—Control over them by Food, Clothing, and Shelter.—Source of Animal Heat.—Effect of Variations in the Food and in the respired Medium, both as respects its Nature and Rarefaction.—Hybernation.—Starvation.—Artificial Reduction of Temperature by Blood-letting.—Principles of Reduction of Temperature.—Radiation.—Contact.—Evaporation.—Their Balance with the Heating Processes.—Local Variations eliminated by the Circulation.—Control by the Nervous System.—Its physical Nature.—Allotropism of Organic Bodies.

Owing to the earth's diurnal rotation on its axis, and its annual movement of translation round the sun in an orbit inclined to the equator, variations of temperature arise, the vicissitudes of summer and winter, day and night.

Variations of external temperature.

In these variations all objects upon the surface of the planet participate; organic forms are no exception. As the heat of the medium in which they live ascends or descends, theirs follows it at a rate dependent on their conductibility.

Like mineral substances, the more lowly forms of life submit to these changes. They have no provision for check or compensation. In summer, the temperature of the stem of a tree rises without any restraint; in winter it declines; and, should the point be reached at which those nutritive changes that give motion to the sap cease, nothing is done to arrest the descent, and the whole organism passes into a state of torpor, hybernation, or temporary death.

Organic forms participate in these variations.

Now, since this following of atmospheric temperatures must take place in every organism as well as in every mineral body, the construction of one having a uniform mode of existence in all climates and all seasons implies a resort to some subsidiary mechanism, which, though it may not check, may yet compensate for these vicissitudes. Accordingly, so nearly is this equalization accomplished in the highly-developed tribes, and a standard temperature so nearly attained for them, that many physiologists, misled by imperfect observations, have concluded that such living beings are emancipated by nature from the operation of physical laws: an erroneous conclusion, for in them that action is only concealed.

Compensating arrangements of the higher tribes.

In different races, the mechanism by which these variations of atmospheric temperature are balanced acts with different degrees of perfection. On this a subdivision has been founded, and animals classified as the cold and hot blooded. We are not, however, to attach much importance to such an arrangement: it is rather imaginary than founded on any real distinction. In man, the temperature is near 100°; in fishes, it is about that of the water in which they live. Insects, in their larva and pupa condition, are cold-blooded; in their perfect condition, hot.

Cold and hot blooded animals.

We have now to explain what physical principles are resorted to in solving the problem of maintaining an organic form at a constant temperature in a medium the heat of which is variable; and as we may reasonably anticipate that these principles are the same in every tribe of life, it will facilitate our investigations to commence with the simplest cases first.

There are two periods in the life of a plant during which it simulates the functions of an animal in maintaining a temperature higher than that of the surrounding air. These periods are, 1st, at the germination of the seed; 2d, during the functional activity of the flower.

Two periods of heat in plants.

If a mass of seeds be laid together, as in the making of malt, the operation being conducted at a gentle temperature, and with the access of atmospheric air, oxygen disappears, carbonic acid is set free, and the temperature rises forty or fifty degrees. A process of oxidation must therefore have been carried into effect, and to it we trace the heat disengaged, for carbon can not produce carbonic acid without a rise of temperature ensuing. The loss of weight which a seed exhibits is therefore due to its loss of carbon, and the whole effect is explained in the statement that atmospheric oxygen has united with a portion of carbon contained in the seed, producing carbonic acid gas and an evolution of heat.

Heat of germination.

Again, during flowering, the same action is repeated. The flower removes from the surrounding air a portion of the oxygen it contains, and replaces it with carbonic acid, the temperature rising, as accurate experiments have proved, in absolute correspondence with the quantity of oxygen consumed. Nor is this elevation insignificant. A mass of flowers has been observed to raise the thermometer from 66° to 121°.

Heat of inflorescence.

If thus the disengagement of warmth is the result of oxidation, it must depend on the presence of air, and be regulated by the rapidity with which oxygen can be supplied. As we pass from the consideration of plants to that of animals, we discover that the production of heat must be connected with the power and precision with

Oxidation the cause of these elevations of temperature.

which the respiratory apparatus works, for it is through its agency that air is introduced. Extensive observation accordingly establishes a close correspondence in each animal tribe between the quantity of heat produced and the capability of respiratory apparatus. The lower tribes breathe slowly and are cold. Earthworms are only a degree or two warmer than the ground; and even among vertebrates, fishes are only two or three degrees warmer than the water, a lowness of temperature in a great measure depending on the high cooling agencies which that liquid exerts, its specific heat, and the facility with which currents are established in it. However, even in these cases the production of heat depends on the power of the respiratory engine. The bonito can keep its heat 20° above that of the sea, and the narwhal maintains a steady temperature at 96°.

Connection of respiration and heat.

The organic operations involved in nutrition, and also the retrograde changes of decay, can only go on at their accustomed rates so long as standard limits of temperature are observed. The proper progress of the actions of life implies a corresponding adjustment of heat, and this irrespective of the mere size of the animal. Even those that are microscopic must come under this rule. When the temperature of a liquid containing infusorials is caused to descend to the freezing point gradually, the last portions which solidify are those which surround each of these little forms; a drop is kept liquid by the heat they disengage. In the same individual, the absolute temperature will depend on its respiratory condition; thus insects, in passing through each of their stages of metamorphosis, present a definite condition as to their heat: the larva of the bee may be only two degrees above the air, while the perfect insect is 10°. Whatever accelerates the introduction and expulsion of the air, increases the warmth; so a bee shaken in a bottle, and kept in a state of constant muscular exertion, will raise the temperature contained therein far higher than if he remains inactive. Among insects, those having the largest organs of respiration have always the highest temperature; and, since muscular motion implies destruction of muscular tissue by oxidation, and therefore development of heat, we should expect to find, as is actually the case, that animals possessing the highest powers of locomotion will possess also the highest temperature. Of all, therefore, birds, the endurance and energy of whose powers of flight result from the perfection of their respiratory mechanism, have the highest temperature. It is about 110°. Yet even here there are differences: the sluggish barn-door fowl has not the heat of the energetic swallow.

Invariability of organic action implies a definite temperature.

Variations of heat with variations of condition.

The standard temperature of man is usually stated to be 98°, but from this mean it ranges within certain limits upward and down. Much depends on the state of the health; of course, every thing

Temperature of man.

on the respiration. In fevers it will rise to 105°; in tetanus it may reach 110°; the contrary in asthma, when it may sink to 82°, owing to imperfect access of air; in cyanosis to 77°, owing to imperfect aeration of the blood; in Asiatic cholera to 75°, owing to the non-reception of oxygen by the cells in their diseased state. It also varies with the period of life: in the new-born infant it is 100°; it presently sinks to 99°, and rises during childhood to 102°. Mental exercise in the adult increases it, bodily exertion still more. The special degree varies with the point on which the observation is made: the limbs are colder than the trunk, and this is the more marked as the point is more remote. On the leg the temperature may be 93°; on the sole of the foot, 90°; while that of the viscera is 101°.

Resistance of the human organism to extremes of temperature.

In his residence in different climates, man is exposed to variations of temperature which extend over a scale of 200°. Toward the poles the cold of winter is often −60°; in the tropics the heat of summer +130°. For a short period his power of resistance is greatly beyond what these numbers would indicate; he can enter with impunity an oven heated to 600°, provided the air is dry. In these cases, though excessive evaporation from the skin moderates the effect and keeps it within bounds, there is always a marked rise of temperature of the whole body. In a corresponding manner, exposure to cold produces depression, as shown in Dr. Davy's observations. At 92° of the air, a thermometer under the tongue stood at 100½°; at 73° it stood at 99°; at 60° it stood at 97½°.

Diurnal variation in the heat of man.

Among these variations there is one class which calls for critical attention. It is the diurnal variation; less marked in man, who instinctively makes provision against it, but well shown in the case of fasting animals. This illustrates, in an interesting manner, the controlling influence of external conditions; for if exposure to a high temperature, as that of an oven, compels a rise of the heat of the whole body, in spite of the conservative arrangements, and exposure to extreme cold compels a descent, we ought to expect that exposure to more moderate degrees would, in like manner, produce an impression.

The old astrologers were therefore not altogether wrong when they affirmed the doctrine of planetary influences. The diurnal temperatures of a locality, as dependent on the position of the sun, are expressed in the system of man. The minimum of heat for the night, and the maximum for the day, find a correspondence in the decline of animal temperature at the former, and its rise at the latter period. The experiments of M. Chossat on birds submitted to absolute starvation showed that, though in their normal state, at the commencement, the variation between midnight and noon was only 1½°, it gradually increased to 6°, until at

last, the generation of heat wholly ceasing, the temperature gave way rapidly just previous to death.

If, therefore, it was possible for life to continue without the evolution of animal heat, it would be with the body as it is with the stem of a tree. It would follow the thermometric variations in the air, the maxima of heat and cold being somewhat later than the aerial ones, and within narrower limits, by reason of the low conducting power. The nearest approach to this is in cases of absolute starvation, and though in man the effect is masked by the due taking of food, it none the less exists. In human communities there is some reason beyond mere custom which has led to the mode of distributing the daily meals. A savage may dispatch his gluttonous repast, and then starve for want of food; but the more delicate constitution of the civilized man demands a perfect adjustment of the supply to the wants of the system, and that not only as respects the kind, but also the time. It seems to be against our instinct to commence the morning with a heavy meal. We break fast, as it is significantly termed, but we do no more, postponing the taking of the chief supply until dinner, at the middle or after part of the day. If men were only guided by views of economy of time saved for the pursuits of business, or if, on this occasion, they put in practice the rule they observe on so many others, of never postponing the gratification of their desires, the first affair of the morning would have been an abundant repast. But against this something within us revolts, and that in all classes, the laboring, the intellectual, the idle. I think there are many reasons for supposing, when we recall the time which must elapse between the taking of food and the completion of respiratory digestion, that this distribution of meals is not so much a matter of custom as an instinctive preparation for the systemic rise and fall of temperature attending on the maxima and minima of daily heat. The light breakfast has a preparatory reference to noonday, the solid dinner to midnight.

Influence of food in adjusting the temperature.

Once more I would remark, that we must not be deceived by the masked aspect which the system in this matter presents. Its diurnal variations are concealed by agencies brought specially into operation for that purpose, but they exist in the physical necessities of the case; and herein, I believe, we have a first glimpse of the cause of those periodicities, which physicians from the earliest times have remarked; for, though the nervous system, both in a state of health and disease, may seem to be their origin, it is not impossible that its changes are connected with variations thus taking place in the external world.

Connection of variations of heat with organic periodicities.

We have next to consider the effect of the annual variations of temperature, which reach their maximum soon after

Annual variations of heat.

mid-summer and their minimum soon after mid-winter, the manner in which the system comports itself under them, and the means which instinct and experience teach us to employ in providing against them.

Effect of annual variations on man.

The tables of mortality show that there is a loss of life at the annual maximum and minimum of temperature which greatly exceeds the average of any other period. In England and Belgium, where the mean temperature of the summer months is moderate, this is not so strikingly marked for those months, and the chief loss falls upon the winter; but in New York, which has a summer corresponding to that of the south of Europe and a winter like that of the north, the effect of these extremes becomes so obvious as even to be popularly connected with the position of the thermometer above or below 55°. Among infants and the aged, whose controlling powers over temperature are imperfect, these effects are most distinctly witnessed; but among healthy adults, and even in Europe, we can detect them on critical examination. Thus, in Brussels, the monthly mortality for January being taken as 105, that for July is 91, for August 96, and for October 93; and it is to be recollected that these are the residual traces of the operation of cold and heat after all the precautions have been used to ward them off. I might make here the same remark that was made when considering diurnal variations, that the true effect is so masked and concealed that we are liable to undervalue it, and do not properly appreciate this tax put upon the system.

Control over annual variations by food, clothing, shelter.

These annual variations of external temperature are chiefly combated by food, clothing, and shelter. The dietetic changes we make between winter and summer are founded upon the principle of using more combustible food for the former, and less combustible for the latter season; and, since the calorific effect of an article of food greatly depends on the quantity of oxidizable hydrogen it contains, the winter diet has more of that element than the summer. Partly thus by varying the nature, and partly by varying the quantity of the food, we can effect a compensation to a certain extent.

Of the manner in which the diet-compensation is aided by variations in clothing little needs to be said. The experiments of Count Rumford established the fact that the conductibility of summer clothing is greater than that of winter, and therefore its resistance to the escape of heat is less. It is sufficient merely to allude to the control which is gained by difference of thickness in the garments, and by their amount or quantity. We instinctively make these adjustments to meet the existing exigencies, and, as far as may be, in this manner aim at a medium effect.

The check upon external temperature by the use of clothing was doubtless one of the first contrivances of the human race. Even of savage life it is a cardinal feature. The check by adjustment of diet belongs to a

civilized state, since it implies a certain control over the animal appetite and personal self-denial. Though great improvements in both of these will doubtless hereafter be made, when the principles of their operation are more generally and better understood, they must, even in their present condition, be regarded as having reached a higher perfection than the check by resorting to shelter. The art of constructing dwelling-houses may be said to be yet in its infancy in all parts of the world, and yet in no particular is the physical condition of females and children, and especially of the sick, more nearly touched. It is only within our own times that attention has been drawn to the proper methods for the admission of warmth, and air, and light; the hygienic influences of furniture and decoration are unknown, beyond, perhaps, a popular impression that it is unhealthy to be in a recently-painted apartment, inexpedient to sleep in a chamber where there are flowers, and unpleasant in summer to have a carpet on the floor, because it looks warm, and is thought to generate dust. The owner of a palace, on which wealth has been fruitlessly lavished, finds, on a cold day, that he can not obtain from his parlor fire the necessary warmth unless by alternately turning round and round. The testy valetudinarian sits in his easy-chair, tormented by drafts coming in from every quarter. In his vain attempts to stop the offending crevices, it never occurs to him that his chimney is a great exhausting machine, which is drawing the air out of the room, and that his means of warming and ventilation are the most miserable that could be resorted to, since radiation can warm only one side of a thing at a time, and fresh air under those conditions can only be introduced by drafts.

Existing imperfections of shelter.

To warm rooms by contrivances such as the open fire-place or stove is obviously unphilosophical, since the effect of these is to exhaust the air of the apartment. The modern method of warming by furnaces, which act by throwing air duly moistened and of the right temperature into the rooms, and therefore by condensation, is clearly a better system, since it not only puts an end to all drafts, the tendency being to force air out through every crevice instead of drawing it in, but it possesses the inappreciable advantages of giving uniformity of warmth, a perfect control over the degree of heat, and likewise over the nature of the air, which need not be drawn from the cellar, or the contaminated impurity of the street, but by suitable flues from the free and clear air above. Ventilating contrivances which can cheaply and effectually force a supply of artificially cooled air in the summer, and warm air in the winter, into dwelling-houses, are still a great desideratum.

Of artificial warmth.

By the aid of diet, clothing, and shelter, we are able to effect an almost complete compensation for the changes of diurnal and annual temperatures, and even to occupy any climate of the globe. It is the manage-

ment of caloric which makes man what he is, and constitutes his special prerogative; his degree of skill therein is the measure of his civilization. The distribution of plants and animals, or, rather, their limitation within fixed boundaries, depends on the distribution of heat, but from these restraints man is free, because he can control temperatures.

From these considerations of the effect of external heat on the human mechanism, we return to a more critical examination of the modes by which heat is generated, and its degree regulated in the body.

Source of animal heat.

In every instance we assert that the production of animal heat is due to oxidation taking place in the economy, and giving rise to carbonic acid, water, and other collateral products. It is not necessary to attach any weight to the experiments of Dulong, which seemed to indicate that not more than four fifths of the heat actually produced could be owing to the oxidation of carbon, nor to those of a like kind of Despretz. The method they resorted to for the measurement of the disengaged heat was open to error; the numbers they employed as representing the combustion heats were incorrect; nor did they make any allowance for other substances, such as sulphur and phosphorus, which are simultaneously oxidizing, and the products of their combustion escaping by the kidneys.

Effect of more combustible aliment, as alcohol.

Reduced to its ultimate conditions, the evolution of animal heat depends on the reaction taking place between the air introduced by respiration and the food, and as either one or other of these is touched, the result may be predicted. If, for example, into the digestive canal alcoholic preparations be introduced, they are absorbed, by reason of their liquid condition and diffusibility, with readiness. The combustibility of alcohol, and the amount of heat it yields, are so great, that the primary effect of the oxidation which ensues is a warmth or feverish sensation. By reason of the changes which are now taking place so actively in it, the blood circulates with unwonted rapidity, and the supply to the brain increasing, that organ exhibits an unusual functional activity. But this display of intellection is only temporary, and an opposite condition soon comes on, for, more carbonic acid accumulating in the blood than the lungs can get rid of, the depressing effects of that body commence, and eventually the symptoms of poisoning by it ensue.

Effect of a more energetic supporter of respiration than air.

Not unlike this is the train of effects which arise when, instead of varying the nature of the article ingested, we vary that of the gas respired. An energetic supporter of combustion, like the protoxide of nitrogen, gives rise to a feverish glow, cerebral activity, to be followed eventually by a deep depression, the poisonous influence of the carbonic acid produced being exhibited. After a while the system casts it off, and recovers its condition of health completely.

If there be an abstinence from food, since the introduction of air by respiration goes on without abatement, the body itself must undergo oxidation, lose weight, and emaciation occur. Its tendency to follow the diurnal variations of temperature become more and more strikingly marked as the process of starvation goes on, and finally a rapid and unchecked decline of the heat ensues. Yet even then life may be preserved by the application of sufficient external warmth, and from an extreme condition of attenuation an animal may be rescued by the use of food; but for such a recovery the external warmth must be continued until there has been time for digestion and absorption to take place. If, however, such an extraneous aid be not duly applied, the temperature of the starving animal goes on diminishing, and he dies of cold.

A starving animal dies of cold.

The doctrine we are here inculcating, that animal heat is due to oxidation in the system, is still further strikingly illustrated by what might be termed starving the respiration. As cold is felt from want of food, so also it is from want of air. In ascending high mountains, the effect upon the system has been graphically expressed as "a cold to the marrow of the bones;" a difficulty of making muscular exertion is experienced; the strongest man can scarcely take a few steps without resting; the operations of the brain are interfered with; there is a propensity to sleep. The explanation of all this is very clear. In the accustomed volume of air received at each inspiration, there is a less quantity of oxygen in proportion as the altitude gained is higher. Fires can scarce be made to burn on such mountain-tops; the air is too thin and rare to support them; and so those combustions, which should go on at a measured rate in the interior of the body, are greatly reduced in intensity, and hence the sense of a penetrating cold. Such journeys, moreover, illustrate how completely the action of the muscular system, and also of the brain, is dependent on the introduction of air; and under the opposite condition of things, where men descend in diving-bells, though surrounded by the chilly influences of the water, they experience no corresponding sensation of cold, because they are breathing a compressed and condensed atmosphere.

Effect of respiring rarefied air.

The respiratory apparatus of certain animals permits a reduction in the amount of air introduced under exposure to a due degree of cold. Such animals are said to hybernate. At the coming on of winter their adipose tissues are engorged with fat. As they pass into their annual sleep, the rate of their respiration falls. The marmot, which in activity will make 140 respirations in a minute, makes now but 3 or 4; the temperature of the body descends, and combustion of the store of fat goes on more slowly. Yet it does go on, for, toward spring, the animal has become very lean; sufficient heat is disengaged to

Phenomena of hybernating animals.

permit the blood slowly to circulate, and so barely to keep up the functions of life. If, however, the stock of material available for combustion is insufficient, the animal dies.

Reduction of temperature by blood-letting and in morbid states. Although we can not interfere with the rate of respiration, we can affect the quantity of air introduced into the system by artificial means, as in the operation of blood-letting; for though, after blood has been drawn, we may make the normal number of respirations, 17 in a minute, and for each introduce 17 cubic inches of air, we have diminished the number of discs, which are the carriers of oxygen; and, as the experience of physicians in all times has shown, there is no method so effectual in reducing any unusual or febrile temperature. So, in like manner, in Asiatic cholera, the marble coldness which the body presents is attributable to the loss of function of the discs, and the consequent abatement in the quantity of oxygen introduced.

Mechanism for reducing the temperature. Thus far we have considered the means which the animal mechanism possesses for raising its own temperature; it remains to show how it can also regulate it. For any thing that has thus far been said to the contrary, the combustions or oxidations which are continually going forward should establish a constant rise, and there must therefore be some principle of restraining such a rise within due bounds. Considering also the incessant vicissitudes of atmospheric temperature, a constant degree could not be maintained unless the system possessed the means of depressing as well as elevating its heat.

Effect of covering as respects conductibility. That the means of regulating the heat are purely physical, we should expect for many very obvious reasons. Economy of heat is accomplished by non-conducting material. On this principle, hair, wool, and feathers act by excluding the contact of the atmosphere, their low conductibility being brought into operation. In many cases, the manner in which this is done is clearly intentional. Thus the down which is placed on the breast of a water-fowl is to screen off the chilling influence of the water, which is there chiefly felt as the bird swims on the surface. The deposits of fat in whales, their blubber, at once affords a protection through its imperfect conductibility, and is also a store of combustible material for the purpose of respiration.

General cooling agencies. The chief cooling agencies in animals are, 1st. Radiation; 2d. Loss of heat by warming the expired air; 3d. Loss by contact of the cold external air; 4th. Evaporation. The circulation of the blood tends to establish an interior equalization, so that local variations are soon obliterated; for, through whatever part the blood may flow, it attains the temperature thereof, and, passing in succession from part to part, equalizes the heat of all.

It would be useless to offer any proof that a living being, like an in-

organic mass, loses or gains heat, as the case may be, by radiation. Since, however, in man, the temperature is usually higher than that of the surrounding medium, the result of this action is that cooling takes place. With regard to loss of heat by warming the expired air, it may be observed that, whatever the temperature of the external air may be, it is raised to that of the lungs after it has been brought into the respiratory passages. This constitutes, therefore, a cooling agency of variable power, for the loss will be greater as the external heat is lower: if the atmospheric temperature rose to 98°, loss in this manner would cease. Recalling what has been said respecting the mode in which air is introduced, it is plain that this loss will chiefly fall upon the nasal passages, the trachea, and larger ramifications of the bronchial tubes; for, by the time the volume inspired has made its way beyond that limit, its temperature must be nearly that of the body. The contact of the cold surrounding air, and more particularly of currents which may be occurring in it, act chiefly upon the skin, and it is in preventing this loss that clothing becomes so efficient. The difference we so frequently notice between the indications of the thermometer and our own sensations are, for the most part, dependent on these currents. A temperature of 50° below zero can be sustained without much inconvenience if the air is perfectly calm, but not so if there is any wind. Of all the cooling agencies, evaporation is, however, by far the most energetic. From the skin and the air cavities, large quantities of the vapor of water are exhaled. As the external heat rises, the sudoriparous tubes act with increased energy, and pour out their excretion as drops of sweat faster than it can be removed. Their length has been estimated at 28 miles. Since, at the temperature of the body, the heat of elasticity of the vapor of water is 1114°, this continued vaporization from the skin and lungs is one of the most powerful sources of refrigeration.

Of radiation.

Heat given to the expired air.

Contact of the surrounding air.

Cooling by evaporation of water.

It may be well to direct a closer attention to the special action of the air passages and skin as concerned in these cooling processes. The diurnal loss of water, by both organs conjointly, is usually estimated at 3½ lbs., of which the pulmonary exhalation constitutes about one third, and the cutaneous about two thirds. The skin acts in a variable manner, losing more or less water as the external air is dryer or more damp. The removal of water therefore becomes a complex operation, in which three different organs are concerned —the skin, the lungs, and the kidneys. Of these, the skin acts meteorologically and variably, as has been just remarked, and the respiratory organs for the most part uniformly. But since it is requisite, in the normal operations of the system, that the diurnal average of water should be removed, the variable action of the skin throws a variable action upon

Variability in the action of the skin.

Vicarious action of the kidneys.

the kidneys, for the excess that the skin can not evaporate must be strained off by these organs. In this regard the kidneys act, therefore, vicariously for the skin; and in hot weather, when the cutaneous losses are great, but little urine is discharged; but in cold weather, when the cutaneous loss is diminished, the quantity of the urine is increased.

Evaporation in the air passages.

I think, however, that as regards the respiratory organs, a distinction should be made in their mode of action. In reality, they operate in a double way. 1st. They act, so far as the nasal passages, the trachea, and larger ramifications of the bronchial tubes are concerned, meteorologically, and therefore variably, for the introduced air possesses the existing atmospheric temperature; is at one time warm, and at another cold; yet, since it always leaves these passages at 94°, it removes from their surfaces sometimes less and sometimes more heat; but it is not so with the action going on in the air-cells, the temperature of which, and of the air they contain, is always uniform; and as water vaporizes into them, it must always do it at a uniform rate, and remove as its caloric of elasticity a uniform amount of heat. I therefore decompose the loss of heat by the respiratory organs into two portions: one, which is constant, and taking place in the cells; the other, variable, occurring in the large air-ways, and, being meteorological, coincides in this respect with the cutaneous loss. In considering the diseases of the respiratory organs, it is well to keep this distinction in mind.

Balance between the heating and cooling arrangements.

The establishment of the equilibrium of temperature in an animal is effected by the mutual operation of the heating and cooling arrangements. More or less heat, as the system requires, may be furnished by promoting or retarding the oxidation of respiratory material; and since a living being, like an inorganic mass, is subject to every external influence, its temperature tending to rise or fall as diurnal, or annual, or seasonal changes may be, these, as well as its own interior variations, are held in check by the cooling or warming powers it can exert. Local differences within itself are eliminated in an indirect, but still very effectual manner, by the circulation of the blood; and, considering the range of variation to which it is exposed, and the frequency of the changes, the required equilibrium is admirably secured.

Elimination of local variations by the circulation of the blood.

Control of the nervous system.

I have reserved for a more special and prominent consideration the influence which the nervous system exerts over animal heat, since it is upon this that many have been disposed to deny the great truth that the heat of the body arises from oxidation. They say that it is produced by the nerves. Even a mental emotion gives rise to disturbance of temperature, and the face may be cover-

ed with blushes. Moreover, as experiments have proved, on cutting a nerve the temperature of the parts it supplies declines; on injuring the great nerve centres the temperature of the whole system lowers, even though artificial respiration may be kept up. In cases of paralysis, the temperature of the disabled part may be very much lower than that of the sound. A paralyzed arm has shown a surface heat of 70° only, while the sound one has been at 92°. It is also said of decapitated animals that they cool quicker when artificial respiration is kept up than when they are let alone.

All this may be very true, yet it is very far from proving that the nerves are the generators of animal heat. The engineer of a locomotive can regulate the speed of his train and control the production of steam by throwing more or less fuel on the fire, or by supplying it with more or less air; but does any one impute the production of the heat to him? If an accident should throw him off, thereby establishing a sort of analogy between his machine and the decapitated animals we have referred to, the stoppage that would soon ensue, and the dying out of the fire, would by no means prove that he made the heat!

And so with the nervous system, its function is not a generative, but a controlling one. It determines in what way the combustive or oxidizing actions shall go on, but that is a totally different affair from forming the heat.

Before specifying more particularly the views I entertain on this subject, I will remark, that the most superficial consideration satisfies us that oxidation in the system goes on in a regulated way. There is not an indiscriminate attack made by the arterial blood on whatever is next before it, but those particles only are removed which the needs of the system require. This therefore implies some overriding or superintending agency, which can save one atom from destruction and surrender another. The portion assaulted may, to all appearances, be identical in physical aspect and chemical constitution to an adjacent one that is passed by. There seems to be an arrest or suspension of affinity in one case, and its ready satisfaction in the other.

Physical analogies to this control of the nervous system.

There are some well-known facts in natural philosophy which throw a flood of light on this obscurity. If a piece of pure zinc be placed in a glass of acidulated water beside a piece of copper, so long as the metals are kept apart no action whatever ensues; but if a conducting thread is laid from one to the other, the zinc instantly begins to oxidize, clouds of hydrogen gas bubbles rise from the copper, and the thread becomes at once red-hot and magnetic. On lifting the communicating thread all these actions cease; on restoring it they instantly recur. We think we explain them by saying that they are all due to the decomposition of water by the zinc. But

why was the zinc passive when alone, and why did it assume this activity when merely touched by another metal? Does not all this serve to show that substances may be, as it were, in a quiescent state, and on the application of what may perhaps seem the most insignificant cause, may suddenly assume activity, and forthwith satisfy their chemical affinities? There is nothing in the graduated oxidations going on in the system more obscure or more unaccountable than the phenomena of a simple Voltaic circle. Their effects are almost parallel.

Allotropism of bodies.

All elementary substances appear to have the quality of assuming active and passive conditions. Carbon, moreover, presents many intermediate forms. As diamond it is extremely incombustible, and is set on fire with difficulty even in oxygen gas; as lampblack it will kindle spontaneously. With these differences in its relations with oxygen, it also exhibits great variations in its optical, calorific, mechanical, and other properties. These transitions of state may be induced by various causes, especially by the agency of what are called the imponderable principles, as by rise of temperature, and exposure to the sunlight. Thus, in the case of chlorine, I have shown that, though it refuses to combine with hydrogen so long as it is in the dark, an exposure to indigo-colored light will cause it to unite with explosive energy with that substance; and these peculiarities are retained by bodies when they go into union with each other. Thus there are two forms of phosphorus, the one active and shining in the dark, and therefore readily oxidizable; the other passive, not shining in the dark, and with therefore a less affinity for oxygen; and these severally give rise to two varieties of phosphureted hydrogen, which, though having the same composition, yet differ in this respect, that the one containing the active form of phosphorus is spontaneously combustible in the air, but the other, which contains the passive form, is not spontaneously combustible. Phosphorus is thrown from the active to the inactive state by mere exposure to the more refrangible rays of the sun.

Allotropism of organized bodies.

The properties here spoken of have been designated by Berzelius as the allotropism of bodies. I have endeavored to prove that allotropism is the true cause of many of the obscure facts which we meet with in the animal mechanism; for it is very clear that something so modifies the relations of the tissues to oxygen that they are not indiscriminately destroyed by it, but these parts yield in a measured or regulated way; and since, in inorganic substances, the influence of the imponderables can compel the assumption of an active or passive state, there is nothing contradictory in imputing to the nervous system a similar power.

In this manner we may therefore conclude that, so far as tissue destruction is concerned, the nervous system possesses a governing or con-

trolling power; that by keeping parts in states answering to the passive and active conditions of inorganic chemistry, it can suspend the action of the respired oxygen or permit it to take effect. This controlling power is, however, altogether distinct from a generative one, and all the heat disengaged is due to oxidation. It is also possible that not only are these states of activity or passivity impressed on the tissues by the agency of the nerves, but also upon the respired oxygen itself, since that gas is no exception to the rule; it also exhibits allotropism. Its passive state is Priestley's oxygen, its active is Ozone. In its transit from the air-cells into the blood it may experience such a change, and have at once communicated to it a high degree of activity.

CHAPTER XI.

OF SECRETION.

SEROUS, MUCOUS, AND HEPATIC SECRETIONS.

Object of Secretion.—Type of secreting Mechanism.—Filtration and Cell Action.—Of Serous Membranes and their Secretions.—Of Mucous Membranes and their Secretions.—Of Hepatic Secretions.—The Liver: its Development and Structure.—Source, Quantity, Composition, Uses, and Flow of the Bile.—Existence of biliary Ingredients in the Blood.—Production of Sugar and Fat in the Liver.—Changes of the Blood-cells in it.—General Summary of the four-fold Action of the Liver: it produces Sugar and Fat, eliminates Bile, is the Seat of the final Destruction of old Blood-cells, and of the Completion of new Ones.—Of the ductless Glands.—The Spleen: its Functions.

Two classes of substances occur in the blood—the products of decay and the elements of nutrition. The equilibrium of the system requires that the former should be removed and the latter appropriated.

The primary object of the function of secretion is this dismissal and appropriation, and therefore, through the latter duty, secretion becomes connected with nutrition. Object of secretion.

The elementary type of a gland or organ of secretion consists of a sac, on the interior of the wall of which a network of arterial ramifications is spread; this delivers its blood into a similar network of veins. Type of a gland. The matter which the gland is destined to separate oozes from the arterial capillaries into the interior of the sac, and is delivered through the neck or mouth thereof, which may be spoken of as the duct. It will be presently shown that the material which thus finds its way into the interior of the sac is not fabricated by that organism, but is brought to it pre-existing in the affluent current of arterial blood. As our knowledge of the functions of glandular structures becomes more

precise, the less and less does it appear probable that the secreted matter is in any way engendered by the gland itself.

Since, with the exception of the lungs, which excrete carbonic acid and vapor of water, all the great glands remove the material they are concerned with in a state of liquid solution, it follows of necessity that the blood of the artery supplying the gland, and that removed by the vein from the gland, differ in two respects: 1st. In the peculiar material constituting the solid secreted; and, 2d. In the quantity of water. From the latter cause it must follow that the venous blood will have a greater spissitude than the arterial.

Change in glandular blood.

This elementary or typical form of a gland is but very little departed from in those cases in which the sac is elongated into a tube; and even where this has been extended to an exaggerated degree, the essential principle of action still remains the same.

From the constancy of aspect which glands present, we might be led at first to suppose that their peculiarities of construction determine their physiological action, that the liver secretes bile, and the kidney urine, because they have the special organization which is needful for such purposes. Such a supposition, however, has to be received with much limitation, as is proved by numberless cases of vicarious action. Thus, in morbid difficulties of the liver, the skin will discharge its duty for it in the elimination of the bile; and in derangements of the kidneys, the mammary gland, the mucous membrane of the nose, or even the stomach, will discharge urine. Constructive arrangements have therefore for their object the facilitating of a secretion, but they do not produce it. Thus the liver is far better fitted for separating bile, or the kidney urine, than is the skin for each of these respectively; but if they become incapacitated, the skin is able to act vicariously for them.

Influence of form illustrated by vicarious action.

Though such vicarious action has been denied by some physiologists as being totally incompatible with anatomical indications, a more profound conception of the law of development of these structures may satisfy us that it is in reality a physiological probability, apart from the evidence we have often derived from interesting instances of its actual occurrence. It will be seen, when we treat of the primitive appearance of the different secreting organs, that they are, in reality, all evolved, as it were, from a common surface or membrane; that this primitive surface discharged, though perhaps in a confused way, all their functions collectively; and that in development the ruling idea seems to be the separating out, or localizing upon a determinate spot or region, structures which should have the duty, in a special manner attached to them, of removing this or that particular substance, a centralization or concentration of action thus occurring. There is therefore

Connection of vicarious action and development.

nothing extraordinary that, under the pressure of circumstances, one of the special structures should, in an imperfect way, resume the action which it once enjoyed, while it was yet a part of the common structure; but, however this may be, the cases of vicarious action are too numerous and too well authenticated to admit of any doubt.

Though these vicarious actions may be in a certain degree imperfect, they are of the highest importance physiologically, since they indicate the true nature of the function, and place the influence of structure in its proper attitude.

The separation of material from the blood may, however, for the present, be considered as conducted in two different ways; 1st, by filtration; 2d, by cell action.

Secretion by filtration is, of course, a purely physical act. The transudation of water charged with saline substances, or with more or less of albumen, seems to imply nothing but the escape of pre-existing bodies through pervious or porous membranes. Such a result is presented in the case of the lachrymal gland, the duty of which is to accomplish a definite mechanical operation for the eye in keeping the cornea clear and transparent. This mechanical function is again observed in the case of the serous membranes, and particularly the synovial ones, in which the relief of friction of movable parts seems to be the object aimed at.

Separation of matters from the blood by filtration.

As long as the material secreted clearly pre-exists in the blood, it is needless to refer secretion to any other principle than the simple one of transudation or filtration. It would be unphilosophical to suppose that the lachrymal gland exercises any property for the formation or production of water when by mere transudation copious supplies of that substance can be obtained from the blood.

But secretion is, moreover, perhaps connected with cell life. On the upper part of the intestine of the young chick, a few cells make their appearance about the fourth day of incubation. They are eventually recognized as bile-containing cells from the color of their contents. As the process goes on, the spot they occupy buds off, as it were, so as to produce a blind pouch. This offshoot, with its exterior cells, is eventually, when perfect development is reached, the liver. Secreting organs of this glandular class, and also membranes, possess a general analogy: they consist of a structureless basement membrane, with cells upon its surface, and a supply of blood-vessels. The cells are not persistent, but lead a very transitory life, apparently elaborating the material with which they are charged, and then undergoing rupture or deliquescence.

Secretion by cell action.

Our conclusion respecting the mode of action of secreting cells turns altogether upon the evidence of the power they possess of preparing ma-

terial which did not pre-exist in the blood. Thus, if it should be shown that, under normal circumstances, the elements of bile are not found in the blood, the inference might be drawn that the hepatic cells display a combining, or, as it were, a preparing power; and so likewise in the case of other secreting cells; but the weight to be attached to such evidence is greatly affected by the consideration that the action of each gland or secreting apparatus masks what is really going on in the system. It is possible that we may be scarcely able to discover the traces of substances in the blood, and yet a tendency may exist for their accumulation to a great extent. Thus there can be no doubt that urea would abound through the disintegration of the muscular structures, and the use of nitrogenized food, if it were not for the action of the kidneys. It is the very perfection of that action which so diminishes the amount in the circulation as to prevent us, except with difficulty, from detecting the presence of the ingredient.

Difficulty of detecting matters of secretion in the blood.

Nor is this all, for it ought to be remembered that many of the products of secretion are substances undergoing retrograde metamorphoses, and have therefore, as it were, in themselves, an interior principle of change. It is conceivable that things which did not pre-exist in the blood may yet occur in the secretions, coming there, not through the agency of cell-life, but because of the downward course toward an inorganic condition through which the secretion is spontaneously passing.

Of the more prominent substances in the chief secretions, many indisputably pre-exist in the blood. Urea, cholesterine, casein, are examples. Wherever this occurs, the removal is unquestionably due to mere filtration. Why should it be supposed that the cells of the kidneys have any duty of combining material presented to them into urea, or those of the liver into cholesterine, or those of the mammary glands into casein? As our methods of examining the blood become more perfect, this formative or grouping action, once so largely imputed to the secreting cells, becomes more and more restricted.

The cases in which the influence of cells is indisputable are those which offer to us combinations of progressive metamorphosis. Of these, the most striking instance is the preparation of the spermatic fluid. Perhaps we should not be very far from the truth if we considered all those secretions in which the materials are in a state of retrograde metamorphosis, or in a descending career, as arising by mere filtration, and those which are ascending to a higher grade as due to cell agency; between the two there being an intermediate class, the phase of which is stationary, and in which cells may or may not be necessarily involved, as, for instance, the transmutation of one fat into another, or the preparation of sugar from albumenoid bodies.

Conditions of filtration and of cell action.

The apparatus for secretion is generally conveniently treated of under

two heads: 1st. Membranes, such as the serous and mucous; 2d. Glands, as the liver, kidney. This division is, however, not founded either on structural or functional differences, and is to be preserved merely for the sake of convenience.

A secreting membrane consists essentially of a tunic of connective tissue, affording a nidus for vessels and nerves. Upon this, in the opinion of many anatomists, a thin basement membrane is laid, the existence of which is denied by others. Upon the surface of the basement membrane there is a layer of cells, the form and arrangement of which differ in different regions. In some places the cells are flat, in others cylindroid. Their duration is temporary, one brood succeeding another from germs on the basement membrane. The superficial, and, therefore, the older cells, desquamate or deliquesce, and are replaced by others from beneath. It is usually said that the serous membranes, with the exception of the peritoneum, are all closed sacs, the peritoneum being perforated where the fimbriated extremities of the Fallopian tubes open into the abdominal cavity in the mammalia, and in fishes through the lateral anal openings. The generality of this view is now called in question, both as regards the synovial sacs and bursæ mucosæ, which all belong to this group. Thus Kolliker regards the synovial structures as tubes open at both ends, and attached by their edges round the articular surfaces of the bones.

Of serous membranes and their secretion.

However this may be, even the peritoneum is practically a shut sac. Accumulations of water within it do not escape through the apertures of the Fallopian tubes, nor can air be injected the opposite way.

Serous fluids.

The fluid exuding from the serous surfaces is a dilute albuminous solution, more dilute as it is presented in the ventricles of the brain, and more concentrated in the synovial cavities, its consistency in the latter case being such that it may sometimes be drawn out in tenacious threads. The mechanical qualities of these various exudations permit a certain freedom of motion in the parts to which they are applied. Thus the secretion of the peritoneum facilitates the movements of the abdominal viscera; those of the pericardium and pleura, of the heart and lungs; those of the synovial membranes and bursæ mucosæ, of the joints and tendons.

The nature of serous secretions may be illustrated by the cases of fluids collected from the abdominal and thoracic cavities, &c. They are usually of a faint yellowish color, clear or turbid, reaction alkaline, and sometimes containing so much albumen as to coagulate readily on heating.

TABLE I.

Fluid of Ascites. (From Marchand.)

Water	952.30
Albumen	23.80
Urea	4.20
Chloride of sodium	8.10
Carbonate of soda	2.10
Phosphate and traces of sulphate of soda	0.60
A viscid substance	8.90
	1000.00

TABLE II.

Ascites with Suppuration of both Kidneys. (From Simon.)

Water	978.00
Fat containing cholesterine	1.00
Albumen,	8.40
Alcohol extract	0.30
Spirit extract	1.70
Carbonate of soda and phosphate of lime	1.20
Chloride of sodium and lactate of soda	6.80
Urea	1.20
Loss	1.40
	1000.00

TABLE III.

Pleural Effusion. (From Simon.)

Water	934.72
Fibrin	1.02
Fat	1.05
Alcohol extract, with salts	1.35
Spirit extract, with salts	10.64
Albuminate of soda	17.86
Albumen	31.00
Fixed salts	9.50
Gain in analysis	7.14
	1000.00

To the above may be added the following interesting instances of fl
of hydrocele, in which attention should be particularly directed to the
currence of cholesterine and other bile constituents. In the case
sented in Table IV., the fluid was observed to sparkle when shaken
consequence of the numberless crystals of cholesterine:

TABLE IV.

Fluid of Hydrocele. (From Simon.)

Water	860.00
Cholesterine, with a little margarine and oleic acid	8.40
Albumen	48.30
Albuminate of soda and extractive matter	6.88
Extractive matter soluble in alcohol	2.30
Chlorides of sodium and calcium, a little sulphate and traces of phosphate of lime	72.52
Phosphate of lime and traces of peroxide of iron	.70
Loss	0.90
	1000.00

TABLE V.

Fluid of Hydrocele. (*From Heller.*)

Water	919.20
Albumen	58.00
Free fat	1.60
Soda soap, biliphaein, hæmato-globulin, dissolved hæmatin, and extractive	13.90
Fixed salts	7.30
	1000.00

TABLE VI.

Fluid of Hydrocele. (*From Heller.*)

Water	906.36
Albumen	60.00
Fat containing cholesterine	0.23
Extractive matters, biliphaein, soda soap	24.04
Fixed salts, chiefly chloride of sodium	9.37
	1000.00

TABLE VII.

Synovial Fluid. (*From Frerichs.*)

Water	948.00
Mucus and epithelium	5.00
Fat	0.70
Albumen and extractive	35.00
Salts	9.00
Loss	2.30
	1000.00

Products of secretion pre-existing in the blood.

I have introduced these tables not only for the purpose of exhibiting the nature of the fluid yielded by membranes of the serous group, but also for the sake of the important evidence they offer as regards the function of secretion itself. In the infancy of physiology it was universally believed that the special function of each gland arose from its peculiarity of construction; that thus, by the liver, out of blood in which they did not pre-exist, cholesterine and its allied bile compounds were made; that thus, by the kidney, urea was formed. Even in more recent times a modification of this doctrine has prevailed, and to the cells of which glands are so largely composed, the duty has been attributed of forming special products. In this way, we still constantly speak of the bile-secreting cells of the liver; but the preceding tables indisputably show that these very compounds, cholesterine, biliphaein, urea, etc., may make their appearance in distant places, oozing from surfaces wholly devoid of the supposed special mechanism. In cases in which there occurs structural degeneration of the kidneys, for instance, urea at once makes its appearance in unaccustomed places, as though, when the readiest avenues through which it might have escaped have failed, it bursts forth or oozes out at the weakest point. With such results, the idea of leakage or straining seems to be insepara-

bly connected; and, moreover, an enlarged view of the operation of cell life seems to indicate that the general action of those organisms is to produce a formative result, the grouping of amorphous into organized material, and the elaboration of that material into more complicated and higher forms. But many of the most important constituents of the various secretions are indisputably things which are on the downward career, fast passing to the inorganic state. Many of them, as presented in the bile or in the urine, run through a series of spontaneous changes, which end in the appearance of truly inorganic bodies. For the fabrication of such substances, half inorganic themselves, it is scarcely to be thought that cell life should be necessary; and these, with many other such considerations, recall the observation I made a few pages back, that the more profoundly we study the composition and constitution of secreted fluids, and the more accurately we understand the function of secretion itself, the less are we disposed to invoke the agency of cell life, and to rely the more on the ordinary mechanical act of strainage.

Elective filtration.

That the different secreting surfaces exercise an elective elimination on materials existing in the blood, some permitting the escape of one, and some of another ingredient more readily, may be demonstrated from their action on saline substances purposely introduced into the blood. Thus the iodide of potassium was detected by Bernard in the saliva, pancreatic juice, and the tears in less than one minute, but in the urine and bile not until after an hour. The ferrocyanide of potassium could be recognized in the urine in seven minutes, but not at all in the saliva. In like manner, cane-sugar and grape-sugar appear in the secretions of the kidneys and liver, but not in those of the pancreas and salivary glands. The lactate of iron, injected into the veins, furnishes no iron to the saliva, but both iodine and iron can be recognized in that secretion after the administration of the iodide of iron.

Upon the whole, we may therefore conclude that very many substances are strained from the blood in which they naturally occur by membranes and glands, which, from the circumstance that they are of various construction and possess a different physical nature, are better adapted, some for the removal of one, and some for the removal of another compound.

Of mucous membranes and their secretion.

Among secreting surfaces the mucous membranes are usually enumerated. Strictly speaking, however, they are scarcely so much secreting surfaces as the seat of numberless secreting organisms. They line the interior of the digestive, respiratory, urinary, and generative apparatuses, and are characterized by extreme vascularity. In structure they consist of several different layers or regions, the undermost being submucous cellular tissue, upon which is spread the proper mucous membrane, containing connective and elastic tissue, which affords a nidus for blood-vessels and nerves. Upon this is the basement

membrane, covered with epithelial cells. In many regions this compound structure rises into elevations, as in the intestinal villi, or sinks into depressions, as in the follicles.

Epithelial cells.

The epithelial cells are of different kinds, sometimes flat, giving origin to tesselated or pavement epithelium, and sometimes cylindroid, each cell, in this case, being set vertically upon the basement membrane. In many instances, the cylindroid nucleated cells are furnished upon their outer extremity with vibrating cilia, constituting ciliated cylindroid epithelium. Both forms of epithelium, the tesselated and the cylindroid, coexist in glandular ducts. The origin of the cells is in the basement membrane, from germs arising there; and as the older and therefore superficial cells exuviate or deliquesce, new ones arise to take their places.

Properties of mucus.

After what has been said, it is not necessary to give a detailed description of mucous surfaces farther than to state that from them there is furnished a viscid, glairy fluid, of different shades of color from white to yellow, denser than water, and insoluble therein. Examined by the microscope, it contains granular corpuscles and epithelial cells. Its reaction is alkaline, and its proximate constituent is a substance to which the name of mucin has been given. Derived from different sources, as the nasal, bronchial, and pulmonary surfaces, the intestinal canal, and the urinary and gall bladders, it exhibits specific differences. Its quantity is often greatly increased by morbid causes, as, for example, in catarrh, its composition likewise varying at different stages of the same disease. Its use, for the most part, seems to be the protection of the delicate structure which secretes it. In some positions, as in the intestinal canal, it likewise probably acts in the way of relieving friction of the substances passing over surfaces.

Simple sac-like cell-gland.

Of secreting Glands.—The typical form of secreting cell-gland is a single cell, with its nucleus at the lower end, the other end having become open by deliquescence or dehiscence, and thus constituting a sac. From the nucleus thus situated at the end of the cavity broods of young cells arise. These become more perfect as they advance toward the mouth of the sac. The outer wall, and especially the region of the nucleus, is furnished copiously with blood-vessels.

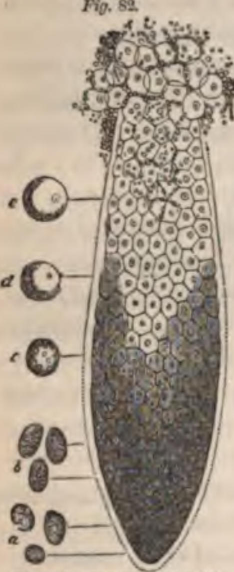
Of such structures, variously modified, the different glands are composed. We shall now proceed to the description of the more important of these, as the liver, kidneys, mammary gland, &c., again impressing the remark that, though all these glands are the seats of myriads of cells, cell life is for increased organization, and secretion is in many instances nothing more than filtration or strainage. We shall endeavor, as the occasion arises, to show, in the case of each gland, what part of its action is due to cell influence, and what to such mechanical permeation.

OF THE LIVER.

Rudiment of the liver.

The first appearance of a bile-secreting organ is the occurrence of yellow cells variously scattered upon the lining membrane of the digestive cavity, as in the hydra. A concentration or localization next ensues, such yellow cells being grouped upon the wall of the intestine at a definite spot. A cœcal projection, in the higher tribes, seems next to force out the yellow cells, bearing them on its exterior, as in the nudibranchiate gasteropods; and as these cœca are prolonged more and more, so, in a more definite manner, does the rudimentary liver appear. In molluscs this partition is sufficiently distinct. The special form which the hepatic apparatus presents in different tribes varies very greatly, though doubtless the principle of construction and of action is always the same. Thus, in insects, the liver consists of long tubes of delicate membrane, covered with secreting cells, small and germ-like near the distant end of the tube, but more perfect at the mouth. These tubes are in relation with an adipose mass, which is probably connected with the origin of the cells. The different condition of these cells, when compared at the bottom and at the mouth of the bile-sac, is well seen in the case of crustaceans, as in *Fig.* 82, one of the hepatic cœca of the cray-fish. The letters at the side show the state of the cells in different positions toward the mouth of the follicle. At *a* they contain yellow biliary matter only; at *b*, oil globules are appearing in them, which become more distinct at *c;* and toward *d* and *e* they present the appearance of ordinary fat-cells. Thus, examined at the bottom of the follicle, the cells are biliary, and as we advance to the mouth they become fatty. (*Leiby.*)

Fig. 82.



Hepatic cœcum of cray-fish.

Development of the liver.

The comparative anatomy of the liver is repeated in its order of development in the high vertebrated animals. In them it is first detected in an evolution of cells upon the intestinal wall, at the point which is eventually to be the place of discharge of the common bile-duct. This agglomeration of bile-cells is next seen to project or bud off through the intrusion of a cœcal pouch. In the amphioxus the condition thus reached remains permanent, and is the counterpart of the liver of a fowl about the fourth day of incubation. The cœcal pouch next sends forth ramifications, which are likewise accommodated with cells, and these, branching again, give origin to a complicated structure. In

this condition, the mouth of the cœcum becomes drawn out and narrowed down, and so forms the rudiment of an hepatic duct.

In man, the liver is the largest gland in the body: it is of a reddish-brown color, dense, and from three to five pounds in weight; convex on its upper, and concave on its inferior surface. It has five lobes: the right lobe, the left lobe, the lobus quadratus, the lobus spigelii, and lobus caudatus. It is held in its position by duplicatures of peritoneum and by a fibrous cord termed its ligaments. Its peritoneal envelope is the cause of its glossy appearance; its cellular envelope extends into the interior as sheaths for the vessels. Five classes of vessels are found within it: the branches of the portal vein, those of the hepatic artery, those of the hepatic veins, the lymphatics, and the hepatic ducts; the latter, converging eventually into a trunk, the hepatic duct, joins with the cystic duct to form the ductus communis choledochus, which discharges its contents into the duodenum, as seen in *Fig.* 83, in which *a* is the gall-bladder, which constitutes a temporary receptacle for the bile, *b* the cystic duct, *d* the hepatic duct, *c* its branches, *e* the ductus choledochus, and *h* its opening into the duodenum.

Description of the liver.

Fig. 83.

The bile-ducts entering the duodenum.

The gall-bladder is wanting in invertebrated animals, and first makes its appearance in a rudimentary condition as a dilatation of the bile-duct: it is absent in the horse, present in the ox; in the camelopard it was absent in one individual, and the next that happened to be examined had two.

The intimate structure of the liver in man is, in many particulars, still imperfectly known, though the attention of the most eminent anatomists has been devoted to it. It may, however, be understood that each hepatic vein, commencing in the substance of the liver, bears upon its capillaries small portions called lobules, from the $\frac{1}{20}$ to the $\frac{1}{40}$ of an inch in diameter, in a manner which calls to mind the arrangement of leaves on a branch, or a bunch of grapes, as represented in *Fig.* 84, *a* being the vein, *b*, *b*, *b*, leaf-like lobules on its branches. Excluding the lymphatics, it may be said that four different systems of vessels are engaged in the liver, the portal vein and hepatic artery, the bile-ducts and hepatic veins. The first pair are afferent, the second pair efferent vessels. The portal vein brings the blood from which bile is to be secre-

Intimate structure of the liver.

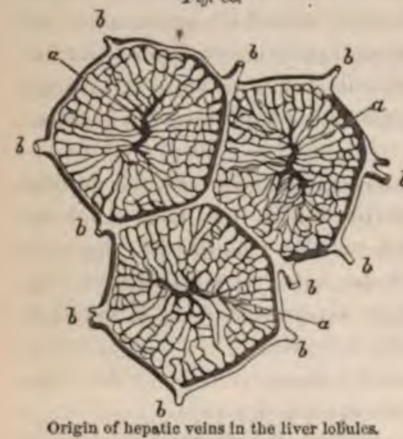
Fig. 84.

Hepatic veins in the lobules of the liver.

ted; the hepatic artery brings aerated blood for the nourishment of the gland; the bile-ducts carry away the biliary secretion which has been separated from the portal blood, and the residue, taken charge of by the hepatic veins, is eventually carried back into the general circulation through the vena cava.

A general idea of the mode of arrangement of the four vessels in the liver may be obtained by recalling the illustration just given, that the lobules are placed on the commencement of the hepatic veins, like grapes on their stalks. The vein originates in the centre of each lobule, as shown at *a a*, in *Fig.* 85, and exhibits there a ray-like kind of divergence. On the periphery of each lobule, at *b*, *b*, *b*, as it were on the surface of the grape, the other three vessels ramify. Of them the portal veinlets dip down into the substance of the lobule. The hepatic arteries likewise enter for the purpose of giving nutrition to the parts. In *Fig.* 86, *a*, *a* are the commencing hepatic or intralobular veins of two lobules; *b*, *b*, the biliary ducts; *c*, interlobular tissue; *d d*, parenchyma of the lobules. With respect to the bile-ducts, which are prominently represented in this figure, it is not positively known whether they proceed beyond the surface, and the manner in which they are related to the secreting cells, and receive the liquid yielded by them, is a subject of controversy. The interspaces between the capillaries that have entered the lobules are filled up with these cells.

Fig. 85.



Origin of hepatic veins in the liver lobules.

Fig. 86.

Origin of bile-ducts on the liver lobules.

It is not known whether the hepatic artery discharges its blood into the portal capillaries, or into those of the hepatic vein, and, for this reason, it is doubtful whether that blood takes part in the secretion of the bile. The secreting cells have nucleolated nuclei, and are about the $\frac{1}{2000}$ of an inch in diameter.

Hepatic cells.

In *Fig.* 87, at *a*, *a*, *a*, their normal state is shown. They are filled with a yellowish, granular soft substance; at *b b* is the appearance of fat

globules, which increase in number and size at *c, c, c, c*. They thus contain both biliary material and oil globules, the quantity of the latter varying with the nature of the food, and in certain diseased conditions occurring to so great an extent as to give rise to the aspect known as "fatty liver." This accumulation of fat is connected with the respiratory function, not only in conditions of disease, but even in a state of health; for, the more energetic the respiration, the more free is the liver from fat.

Fig. 87.

Hepatic cells magnified 400 diameters.

As the chyle passes through the mesenteric glands before it is discharged into the circulation, so do the matters which have been taken up by the vascular absorbents pass to the liver. In Chapter IV. the bile, which is secreted from the portal blood, is treated of as taking part in the function of digestion; but there is another aspect under which we have now to regard it.

Hypothetical spiral course of the bile.

We speak of the circulation of the blood, because, setting out from the heart, it comes back thereto, pursuing a course which returns upon itself. In the same metaphorical manner, according to the views of some, we might speak of the spiral motion of the bile; for those of its constituents, which are first taken from the stomach and small intestine by their veins, appear to pass in the portal circulation to the liver. In that gland a preliminary partition of the constituents of the portal blood ensues, one stream setting off to the general circulation through the hepatic veins, and another, the bile itself, returning to the intestine. In the intestine another partition ensues; the coloring matter of the bile is dismissed with the fæces, and the residue, taken up by the lacteals, passes through the mesenteric glands, and, either by the thoracic duct or otherwise, gets into the blood circulation. It may therefore be perhaps thought that the constituents of the bile have been twice, in close succession, in the digestive cavity, and have been twice absorbed, first by the veins, and then by the lacteals; and that, as it were, a spiral course has been pursued.

The question at once arises, what is the object of such a course? Why is there this return to the digestive cavity? The answer commonly given is, the bile takes part in promoting the operation of digestion. But the return may perhaps be, not for the purpose of inducing digestion, but for the purpose of being acted on or digested itself. The separation of its coloring matter, just alluded to, is a significant fact.

The portal blood, as it is preparing to enter the liver, may be regarded as systemic venous blood, the constitution of which has been altered

through the additions made to it by absorption of matters from the stomach and intestine. We may overlook for the present those contributions it receives from the veins of the spleen and other sources. Regarding it, therefore, as systemic venous blood, charged with certain of the products of digestion, it enters the liver to be acted upon by that gland. The first effect upon it is, in a chemical point of view, well marked. The stream which sets off to the general circulation through the hepatic veins may be said to carry away the whole of the nitrogenized material; for the bile, which is at this point parted out and sent back to the intestine through the biliary ducts, does not contain more than 4 per cent. of nitrogen, and this exclusive of the water which imparts to it its liquid condition. Arrived in the intestine, a repetition of the same process of partition takes place, the coloring matter, which contains nearly the whole of this residual nitrogen, being dismissed with the fæces, and the remaining hydrocarbon taken up by the lacteals along with other fats.

Separation of the portal blood in the liver.

Course and separation of the bile.

The first duty of the liver is therefore a separation of the nitrogenized principles of the portal blood, which are forthwith carried into the general circulation through the hepatic veins and the vena cava. The result is, that there is returned to the intestine a sulphureted hydrocarbon, still containing so much nitrogen as to form a very unstable product, prone even to spontaneous decomposition. In the intestine its nitrogen is wholly removed from it, and the combustible hydrocarbon is then absorbed.

The portal blood, regarded under the aspect here presented, is obviously composed of two constituents: 1st. Systemic venous blood; 2d. Matters obtained from the digestive cavity. We next inquire from which of these the bile is really derived.

From what source is the bile derived?

Besides the presumptive evidence arising from the consideration that if the bile originated from matters which had been just absorbed from the digestive cavity, it would be inconceivable why it should be returned forthwith thereto, its quality of extreme instability marks it out as a substance fast approaching to final disorganization and decomposition. It bears no aspect of a histogenetic or formative body, but, on the contrary, it is on the downward course. We should scarcely expect to recognize it as a primary product of the digestive action, but should seek its probable origin in some source of decay.

Whatever weight may attach to such considerations, we have, in addition, direct evidence which places the source of the bile beyond doubt by referring it to the systemic venous blood, and not to the matters just obtained from the digestive cavity.

During fœtal life, the digestive organs are in an inactive state, but the liver, which is largely developed, discharges its secretion into the intestine. This secretion, which is known as the meconium, is a true bile, as the following analysis proves.

Composition of Meconium. (*From Simon.*)

Cholesterine	160.00
Extractive and bilifellinic acid	140.00
Casein	340.00
Bilifellinic acid and bilin	60.00
Biliverdin and bilifellinic acid	40.00
Cells, mucus, albumen	260.00
	1000.00

Dr. Davy found that the ash left after the incineration of a sample of meconium is of a reddish color, consisting chiefly of peroxide of iron and magnesia, with a trace of phosphate of lime and chloride of sodium.

It does not come from recently digested products.

During fœtal life the liver is therefore discharging the same function that it does after aerial respiration has commenced, that is to say, it secretes bile (meconium) into the intestine; but at this period, since there is no true digestion, the bile can come from one source alone, and that source is the systemic venous blood. There therefore can remain no doubt that, in after life, the same effect takes place, and that the bile is never derived from materials which have just been brought from the digestive cavities.

It comes from the venous blood.

I therefore regard the bile as an excretion of materials which are decomposing and ready to be removed from the system. I incline to the supposition that much of it is derived from the cells of the blood, the life of which is only temporary, for the casein of the meconium is nothing but the globulin of the cells, the two substances being chemically allied, and the predominance of iron in the ash of meconium seems to establish a connection with hæmatin. Moreover, this opinion is supported by the remarkable stability of many of the nitrogenized coloring matters, the analogies between hæmatin and chlorophyl, and particularly by the fact that in the herbivora the coloring matter of the bile is undistinguishable from chlorophyl, and in most other tribes closely allied thereto.

In any discussion of the action of the liver, it is thus to be constantly borne in mind that the portal blood consists of two distinct portions, systemic venous blood and matters absorbed from the digestive apparatus. Derived from the first of these portions, we trace the origin of the bile to the waste of the tissues, or to the blood-cells on their downward career; and hence we arrive at the important conclusion that every proximate constituent of the bile pre-exists in the systemic venous blood.

Attempts to detect cholic acid and bile pigment in the blood.

Lehmann, inclining to the view that the formation of the bile occurs in the liver itself, quotes the experiments of Müller and Kune, who, after tying the portal vein and applying ligatures to all the points of attachment of the liver in frogs, extirpated that organ, and collected the blood of those which survived the operation for two or three days, by amputating their thighs.

It was expected that in this blood, bile pigment and cholic acid would be found if the original formation of those substances took place externally to the liver. Such did not prove to be the case. It may, however, be justly inferred that no reliable conclusion can be drawn after operations of such magnitude and severity.

The alleged inability to detect the constituents of the bile in the blood of the portal vein is probably due to the defects of our analytical processes, for it is very clear from the circumstance that the bile which is poured into the intestine must be reabsorbed, with the exception of its coloring material, either by the lacteals or the veins, or by both, since it is not found in the excrement. Through whichever of these channels it passes, it must therefore regain the general circulation, for it can not be supposed that in the short period of its course it could have undergone complete metamorphosis.

Cause of this difficulty of detecting bile in the blood.

We may therefore assume that the proximate ingredients of bile preexist in the blood, and this conclusion is enforced by the fact that, after tying the vena porta, bile, though in a diminished quantity, is still secreted. The same also occurs in those cases of malformation in which that vessel, instead of ramifying into the liver, empties directly into the vena cava. When there is any failure or delay in the removal of bile from the system, the effects are such as might even be predicted, nervous disturbance ensuing, and eventually all the symptoms of poisoning. The circumstance that this last effect often takes place suddenly, has been by some supposed to be dependent on the necessity for the bile to accumulate, to a certain extent, but it is much more likely that it is determined by the metamorphosis of the decomposing bile having reached a certain point, when special poisonous products have spontaneously arisen from it.

Bile, from whatever animal it may have been derived, contains a resinous soda salt, a coloring material, cholesterine, and mucus. The acid of the soda salt is the taurocholic or glycocholic. The coloring matter in carnivorous and omnivorous animals is brown, the cholepyrrhin of Berzelius; but in birds, fishes, and amphibia, it is green, biliverdin. Strecker makes the curious remark respecting the bile of fishes, that in those which are of salt water, potash salts predominate; and in those of fresh water, soda salts. Among the ultimate elements occurring in the bile, and being of special interest, may be mentioned sulphur, which exists in taurine, of which the composition is C_4, H_7, N, S_2, O_6. It may be obtained from oxgall; it has likewise been made artificially by Strecker from the isethionate of ammonia. It is distinguished by evolving sulphurous acid when burnt in the open air. It does not exist in the bile in an insulated condition, but probably as an adjunct to cholic acid, and has been found in that secretion of both hot and cold-blooded animals. It has,

Constitution of bile.

Constitution of taurine.

however, been asserted that sulphur, and therefore taurocholic acid, does not exist in the bile of the hog.

The bile is secreted more slowly during a long period of fasting, and more rapidly during normal nutrition. To a certain extent, this variable rate depends on the general principle that a gland acts more energetically in proportion as the supply of blood sent to it is greater. If not wanted for the present purpose, the product is stored up, for a time, in the gall-bladder.

Production of bile.

When the bile has been long retained in the gall-bladder, it becomes concentrated through the removal of a portion of its water: it also undergoes a change of color. In animals whose hepatic bile is yellow or brown, the cystic bile has a tendency to green, a change of color dependent on partial oxidation, occasioned by the arterial blood.

Change of bile after retention.

The flow of bile takes place with different degrees of rapidity at different diurnal periods: thus it reaches its maximum in from thirteen to fifteen hours after the last full meal, and then rapidly diminishes.

Period of maximum flow of bile.

Bidder and Schmidt estimate the diurnal secretion in an adult at 54 oz., containing 5 per cent. of solid matter, an estimate which is undoubtedly too high, so far as an average diet and state of health are implied. It is asserted that a diet of flesh tends to produce more bile than one of a purely amylaceous kind. Even the use of a large quantity of water increases its amount, and this as regards its solid constituents. Remedial agents act in various ways. Calomel increases the fluid, but diminishes the solid constituents. Carbonate of soda diminishes both. Again, there are great variations in the rate of its production: the circumstance just mentioned, that its maximum flow is several hours after the maximum digestion, is important as regards the explanation of its formation, showing significantly that it is not directly produced from matters recently absorbed from the intestine, but from the systemic venous blood.

But the liver has other duties to discharge besides the separation of bile. It gives origin to sugar and fat, as is proved by the circumstance that the blood of the hepatic veins is richer in those ingredients than the blood of the portal. In this respect its action seems more particularly to be that it converts other sugars into the particular form known as liver-sugar, which it can also produce from the transforming albuminous bodies; it forms fat from sugar, and makes from certain other fats the special one known as liver-fat. In this duty of forming sugar and fat, it exhibits an inverse power of action; as the production of the one predominates, that of the other declines.

Other duties of the liver besides producing bile.

From the point of view which we have now reached through this description, we are able to see the double duty which this great gland dis-

The liver does not form bile. charges, and must correct, to a certain extent, the popular theory of its action. Does the liver really secrete bile? Is it the business of the so-called bile-secreting cells to withdraw the constituents of that liquid from the blood, and combine them together into this viscid yellow liquid? I think not; for it is a matter of demonstration that not only every constituent of the bile, but the bile itself, pre-exists in the blood, and it is just as unphilosophical to burden those cells with the duty of forming it as it would be to believe that a like agency is needful for the appearance of urea in the kidney. Moreover, we must constantly bear in mind the extreme instability of this substance, how readily the yellow bile of carnivorous animals becomes green by partial oxidation, and the green bile of the herbivora yellow by deoxidation. It spontaneously changes in its downward career, and any differences in quality or character which we might impute to the action of the cells upon it may be equally well attributed to its own inherent principle of change.

For these reasons, I believe that the bile simply transudes from the blood, and that the cells of the lobules have no special relation to it beyond this, that it oozes past their interstices, or, perhaps, by physical imbibition, finds access to their interior. I see no reason that these cells should form it when it pre-exists in the blood, nor does the state of the affluent and effluent blood offer any contradiction to this conclusion. In all discussions of the functions of this organ founded upon a comparison of the portal and hepatic venous blood, the relative quantity of water which they contain, and its great and even rapid fluctuations, should always be borne in mind. As might be expected, portal blood contains far more water, and, even after abundant drinking, the amount in the hepatic venous blood has by no means increased to the extent that might have been expected. It is for these reasons that the bile varies so greatly at different periods in its specific gravity and fluidity.

Manner of removing it.

The blood of the portal vein is, moreover, periodically varying in its constitution, according to the state of activity of the organs from which it is being derived. In the first stages of digestion the stomach is supplying it in unusual quantities, and with the ingredients which its veins have been absorbing from the result of histogenetic digestion. A little later, the same thing occurs with the intestine. At another period the supply from the spleen varies.

Variation in the constitution of the portal blood.

The explanation which Mr. Handfield Jones has recently given of the function of the hepatic cells—that they manufacture liver-sugar—deserves attentive consideration, more particularly if we likewise impute to them the production of liver-fat; for this would attach them rather to the ramifications of the hepatic veins as a part of their instrumental mechanism, and assign them only a very indirect relation to

Function of the hepatic cells.

the bile-ducts. The contradictory statements which have been made by the most eminent anatomists respecting the connection of the bile-ducts and the bile-cells—some believing that the bile-ducts are covered interiorly with the cells; others, that the ducts end on the outside of the lobules; others, that the passages reported to have been seen among the cells are interstitial channels and not proper vessels—make it just as probable, anatomically, that the cells belong to the hepatic veins as that they belong to the biliary ducts.

It is true that there may be a mixed action, and that presence of biliary matter may be necessary to the sugar and fat producing agency. This interworking and mutual dependency of functions is not without a parallel. Thus the lung, viewed as a secreting or excreting gland, has for its object the removal of carbonic acid from the system; but it also discharges another duty, which is dependent for its accomplishment upon the physical or chemical qualities of the hæmatin of venous blood, the introduction of oxygen by aerating or arterializing. But the excretion of carbonic acid and the introduction of oxygen, though separate physiological events, and to be spoken of as distinct functions of the lung, are yet nevertheless interconnected; the one is essential for the accomplishment of the other, and the one effect is made the means by which the other is brought about.

So it may be in the liver: the contact of bile with the secreting cells may be essential to their sugar or fat producing action.

Relation of the deposit of fat and production of bile.

The deposit of fat and the production of bile seem to be inversely as each other. Bidder and Schmidt found that fat animals yield less bile than lean ones, and that when they were fed on fat the quantity was smaller than in the case of animals fed on a less fatty diet. From such facts, the inference has been drawn that the accumulation of fat is in consequence of a diminution of the secretion of bile, and not that the diminution is the consequence of the animal being fat. In such discussions it should, however, be recollected, that the fats do not furnish all the substances required for the production of bile, but only a limited portion thereof. Thus there are reasons for the belief that sugar, lactic acid, or some other allied body is essential to that process, and it is very clear that so too are the materials furnished from the decay of the cells of the blood.

Production of sugar and fat in the liver.

With respect to the production of sugar in the liver, it may be remarked, that the quantity of that substance in the solid residue of the serum of hepatic blood is from ten to sixteen times greater than in the same residue from the portal blood; and in animals undergoing starvation, though no sugar could be found in portal blood, it occurred to such an extent in the corresponding hepatic venous blood, that Lehmann found that its quantity could be determined

by fermentation. From this there can be no doubt that, in the changes which are occurring during the passage of the blood through the liver, there is a production of sugar, and this seems to be connected with a diminution in the quantity of fat; for if an excess of fat and a deficiency of sugar enter that organ, and their quantities are inversely changed at their emergence from it, it would appear that fat may be decomposed actually, as we know is possible hypothetically, into cholic acid and sugar.

Taurine comes from blood-cells.

But with respect to taurine, the adjunct of the cholic acid, since it is a nitrogenized body, we are obliged to seek for it in some other source, and this, it would appear from the facts set forth, must be the regressive metamorphosis of the blood-cells. Taurine has not as yet been detected in the portal blood. It can not be supposed that the sulphuric acid of the portal blood is used by deoxidation in the preparation of free sulphur for the taurine, since, if any thing, the quantity of that acid in the hepatic venous blood is increased. From whatever source it may have been derived, the sulphur of taurine entered the liver in an unoxidized state.

Analogies in plants in producing sugar and fat.

When we reflect that the bile is the product of decay, that it pre-exists in the blood, that on its arrival in the intestine a part of it is cast out with the fæcal matter, it seems very unlikely that an immense cell apparatus, constituting the largest gland in the whole system, should be necessary for its removal. But when we moreover reflect that in the mechanism of plants, from gum, or rather from carbonic acid and water, under the agency of cells in the leaves or other structures, both sugar and oils are formed, we recognize that there is a connection between those organisms and these products.

Influence of the pneumogastric nerve on the quantity of sugar.

M. Bernard's experiments seem to show that the sugar-forming function of the liver may be morbidly increased by wounding the medulla oblongata near the origin of the pneumogastric nerve, or by the application of galvanism to the same part, an artificial diabetes ensuing, and this within a few minutes after the operation, but it usually ceases after two or three days. It is accompanied by a great derangement of respiration, a lowering of the temperature, and a venous condition of the arterial blood. It by no means follows, however, that the excess of sugar observed in Bernard's experiments arises from an increased action of the liver, or an increased energy of the sympathetic nerve: it may be, as Reynoso asserts, attributable to the injury inflicted on the pneumogastric, and diminished respiration. The administration of ether and chloroform, the conditions of old age and fœtal life, the influence of many diseases, as chronic bronchitis, asthma, pleurisy, all present a tendency to the accumulation of sugar in the urine, the sources in each of these cases being attributable to respiratory disturbance; for if any thing occurs to retard or delay the destruction by

oxidation of the sugar, constantly formed by the liver, the accumulation will make its appearance in the urine. The appearance of saccharine matter in that secretion may be equally well attributed to its non-destruction in the system generally as to its over-production by the liver.

This gland, besides producing sugar and fat, is the seat in which the worn-out blood-cells are finally disintegrated, and probably the young ones pushed forward through a certain stage of their development; advantage, moreover, being incidentally taken of the secreted bile, which possesses properties useful though not essential for promoting the digestion and absorption of fatty material, perhaps, also, of imparting a definite course to the transmutation of the semi-digested material in the intestine, and this both as regards nitrogenized, amylaceous, and fatty bodies. Of the influence of the bile in promoting the absorption of fat, the physical experiments which have been alluded to leave no doubt; but that these uses are of a secondary or non-essential kind, and are only taken advantage of in an indirectly economical way, is established beyond all possibility of a doubt by the fact that animals can live for a long time, even for months, without the passage of bile into the intestine, provision having been made for its escape externally through an artificial fistulous orifice.

Destruction of blood-cells in the liver.

These conclusions respecting the functions of the liver are in harmony with the appearances presented by the blood leaving and entering it: the predominance of colorless blood-cells, and of young cells well advanced toward perfection in the former, and of wasted, worn-out ones in the latter; with the fact that the maximum secretion of bile does not take place until more than half a day after the ingestion of food; and that during fœtal life, in which there is no food, either in the stomach or intestine, to be digested, the liver is nevertheless in high activity, and bile is secreted.

In view of all the preceding facts, we may therefore finally conclude that there are at least four distinct operations conducted in the liver; 1. The production of sugar and fat; 2. The separation of the bile; 3. The destruction of old blood-cells; 4. The completion or perfection of young blood-cells, perhaps by receiving their iron. With respect to these it may be remarked,

First. The formation of sugar and fat, either from carbohydrates, or what, in this instance, is more probable, from albumenoid bodies brought by the portal vein, can no longer be doubted. The prevalence of liver-sugar and liver-fat in all that region of the venous circulation included between the liver and the lungs must be attributed to this source. That the sugar undergoes rapid metamorphosis in the pulmonary organs is plainly proved by the effects of irritation of the pneumogastrics, which, interfering with the function of res-

General summary of the action of the liver.

piration, permit this substance to reach the aortic circulation, from which it is removed by the kidneys, a diabetes arising. So far as the preparation and course of this sugar is concerned, the liver is a ductless gland, and, with Mr. Handfield Jones, I believe that the cells of the liver are the agents which accomplish this duty. The production of fat appears to be inversely as that of sugar. In the crustacean bile-sac, *Fig.* 82, we see the gradual stages of its appearance; and the production of both bodies is well illustrated in the life of plants.

Second. The bile is separated from the blood portion of the portal blood, and not from the products of digestion obtained from the chylopoietic viscera. The elements of bile I believe to pre-exist in the blood, and to escape from the portal veinlets to the biliary ducts by mere filtration or strainage. The precise source from which the bile is derived is probably the blood-cells, and in the changes which they are undergoing the spleen is perhaps concerned. If this be so, the bile-duct is as much a duct for the spleen as it is for the liver itself. The bile may almost be looked upon as a hydrocarbon, containing a very changeable and therefore noxious coloring material, which, when the secretion reaches the intestine, is parted from it and dismissed with the fæces, the proper hydrocarbon being taken up by the absorbing arrangement for hydrocarbons, the lacteals, and so sent through the thoracic duct. Perhaps, also, by reason of its special adaptedness for that purpose, it aids in the absorption of other fats.

At this point it may be remarked that the view here presented of the sugar-forming and bile-straining functions of the liver appears to be greatly strengthened by the anatomical construction of that organ. There is no obvious communication between the portal and hepatic veinlets save through cells, but the portal veins and the bile-ducts run in their ramifications side by side.

Third. Whatever part of the disintegration of old blood-cells takes place in the spleen, their final destruction is doubtless accomplished in the liver, this being the immediate source from which the bile itself is derived. Though these metamorphoses are, to a greater or less extent, occurring throughout the circulation, it is in these two great glands that an opportunity is afforded for the destruction to reach its completion, and the resulting product of waste to be removed; nor is there any thing in this view at all contradictory to the opinion I have enforced, that all the constituents of the bile may be found in the general circulation.

Fourth. The liver also aids in the preparation or maturation of young blood-cells in an indirect way. There are certain of the mineral constituents of the disintegrated cells too valuable to be cast away, since they can subserve the duty of entering into the composition of young cells passing toward perfection. As such a substance may be mentioned iron.

This view of the action of the liver appears also to be sustained by the large number of star-like and corrugated blood-cells occurring in the portal blood of fasting animals, and which are replaced by such as appear to be young and perfect in the blood of the hepatic veins. It is not, however, to be supposed that all the iron is economized in this manner; a considerable portion of it accompanies the pigment as an essential ingredient, and is finally discharged through the intestine.

OF THE DUCTLESS GLANDS.

The salivary and sudoriparous glands discharge their secretion directly through ducts. The liver and kidneys have upon their ducts an additional mechanism, the gall bladder in the one case, and the urinary in the other, which serve as receptacles for storing up the product of action in a temporary manner, and so converting the continuous effect of the gland into a periodical result. In each of these instances we may arrive at conclusions of a certain degree of exactness respecting the functions and use of the gland from a study of the secretion it yields; but there are in the system other glandular organs which differ essentially from all the preceding in not being furnished with ducts. These are the spleen, the thymus and thyroid glands, and the supra-renal capsules.

The ductless glands.

Much diversity of opinion prevails respecting the true nature and action of these bodies. From their structure bearing a resemblance to that of the preceding, with the exception of the absence of a duct, many have thought that, like them, they are really secreting organs. Others have supposed that they have a relation to the nutrition of the system, in giving origin to the development of cells, or that they are connected with the organization of the blood itself; and that such is their duty is perhaps rendered probable by the circumstance that some of them, as the thymus and thyroid, exhibit their utmost development when the body is rapidly growing, and diminish when maturity is reached. That they enjoy a community of action, or that their function can be vicariously discharged by other organs, has been clearly established by the result of operations in which one or other of them has been extirpated.

Their supposed functions.

With respect to the spleen, the views of Professor Kolliker are supported by many facts. He supposes that one of the chief functions of that gland is the dissolution of the disorganizing blood-cells preparatory to the action of the liver, in which hæmatin is to be converted into the coloring matter of the bile. In the discussion entered into respecting the origin of the bile, we have come to the conclusion that it is derived from the systemic venous blood, and in the supposition here presented respecting the function of the spleen there is nothing con-

Function of the spleen.

tradictory, for it is to be remembered that the blood of the spleen is a constituent of the portal circulation. It also appears to be a general opinion that the spleen likewise maintains a mechanical relation to the portal mechanism by serving as a receptacle for any excess of blood, and thus relieving the vessels of pressure, or by acting in like manner when there is any obstruction to the passage of blood through the liver.

Analogy of the other glands with the ductless.

As our knowledge of the action of the ordinary glands becomes more accurate, the function of the ductless glands loses much of its peculiarity. As we have already stated, in a certain sense the liver itself may be said to be a ductless gland, for it appears to be one of the constant duties of that organ to prepare sugar from materials in which it did not pre-exist. And this sugar does not escape through the hepatic ducts in company with the bile, but is taken directly into the system through the hepatic veins. But this principle of action is identically what occurs in the case of every ductless gland, and hence it may be inferred that the changes which these impress on the blood are necessary for the development and nutrition of the system. If the doctrine of Kolliker be correct, the spleen is only an appendix to the liver, and the same duct answers as a common outlet for both.

Nature of splenic blood.

The views here alluded to are enforced by the examinations which have been made of the blood of the splenic vein. The following table exhibits the contrast between it, that of the external jugular, and that of the mammary artery.

Constitution of Splenic Blood. (From Scherer.)

	Mammary Artery.	Ext. Jugular.	Splenic Vein.
Water	750.60	778.90	746.30
Albumen......................	89.50	79.40	124.40
Corpuscles and Fibrin....	159.90	141.70	128.90
Loss............................			.40
	1000.00	1000.00	1000.00

From which it appears that the blood, after circulating through the spleen, has lost a large portion of its cells, the relative quantity of its albumen is greatly increased, and, moreover, from being the basic albuminate of soda, the form under which it ordinarily occurs in the blood, it has become the neutral albuminate, as is proved by a turbid appearance on the addition of water, and this state it seems to retain during the portal circulation, for the blood of the hepatic veins exhibits the same peculiarity.

CHAPTER XII.

OF EXCRETION.

THE URINE, MILK, AND CUTANEOUS EXCRETIONS.

Secretion and Excretion.

Of the Kidney: its Structure and Functions.—The Malpighian Circulation.—The Urine: its Ingredients, their Variations and Sources.—Abnormal Substances in it.—The Water and Salts exude by Filtration.—The Cells remove unoxidized Bodies.—Manner of Removal of the Liquid from the Malpighian Sac.

Of the Mammary Gland: its Structure.—Colostrum and Milk.—Ingredients of Milk and their Variations.—Influence of Diet.—Inquiry into the Origin of the Ingredients of the Milk, its Fat, Casein, Salts, Sugar.—Manner of Action of the Gland by Strainage.

Of the Skin.—Structure of its Epiderma and Derma.—Sudoriparous and Sebaceous Glands.—Nails.—Hair.—Ingredients of Perspiration.—Exhalation: its Amount.—Causes of the Variable Action of the Skin.—Its Double Action.—Absorption by the Skin.—General Summary of the Cutaneous Functions.

Distinction between secretion and excretion.

THE function of secretion is very commonly treated of by physiologists under two divisions, secretion and excretion. The former refers to the separation from the blood of those fluids which are required for the uses of the body, and which are therefore still retained; the latter, to those which are effete, and to be cast out as excrementitious matter. Of secretions, the saliva or the pancreatic juice may be taken as examples; of excretions, the urine.

But this subdivision is only one of convenience, and has no natural foundation. The so-called secretions are, in many instances, far from being more highly elaborated bodies; in reality, they are often on their descending career. And among excretions, if milk be enumerated, as it ought to be, since it is a dismissed product of the system preparing it, we have, instead of an excrementitious, a pre-eminently nutritive body.

Nevertheless, since this manner of considering the subject offers considerable conveniences, I have resorted to it for the preceding and present chapters. In this I shall accordingly treat of the urine, the milk, and the products removed by the skin.

OF THE KIDNEYS.

Physical function of the kidney.

The products of waste arising from oxidation in the functional activity of the system, and which are of a non-gaseous kind, the useless materials, saline or otherwise, which have been absorbed in the digestive tract, and carried into the circulation, must be removed. Gaseous substances and vapors may pass away through the lungs, but solid material must be excreted in a state of so-

lution in water. To accomplish this object, a special mechanism, the kidney, is introduced.

From this manner of considering the functional duty of the kidney, it is very clear that a special relation must exist between this excreting organ and the respiratory mechanism, for in the case of animals which breathe by gills, or in those which, though subsequently atmospheric breathers, receive their supply of aerated blood before birth by a placenta, the conditions under which aeration takes place are such as permit the removal of solid material by the respiratory mechanism. The urinary excreting apparatus of an animal breathing air is therefore necessarily burdened with an exclusive duty, which is shared by the gills and the skin in a water-breather.

The kidney in birds, fishes, insects, etc.

In fishes, the renal apparatus is constructed under the condition here indicated, and though in many it appears to be greatly developed, extending as a tubular arrangement from the skull through the abdominal cavity, it is to be regarded as analogous to the Wollfian bodies rather than to the true kidney. In reptiles the proper kidneys appear; in birds they are well developed, but their secretion is, for the most part, a semi-solid substance, chiefly urate of ammonia. The tubular form is presented in both insects and arachnidans, discharging its secretion into a cloaca.

The kidneys in man.

In man the kidneys may be described as a pair of dark-red ovoid bodies, placed one on each side of the vertebral column, in the lumbar region, the right kidney being a little lower than the left. In the adult the kidney is four or five inches in length, and is enveloped in a mass of fat. Blood is brought from the aorta to supply the organ by the renal or emulgent artery, and is carried back by the emulgent vein into the inferior vena cava. During its passage through the kidney there is removed from the blood a liquid secretion, the urine, which, flowing down a long channel, the ureter, is emptied into the bladder, from which it may be periodically removed.

Supra-renal capsules.

The supra-renal capsules are bodies of a yellow-red color placed above the kidneys. They are much larger in the fœtus than in the adult, and doubtless have a reference to the peculiar conditions of respiration obtaining at that time, for, as we have just observed, the renal and respiratory mechanisms are necessarily interconnected.

Minute structure of the kidney.

The substance of the kidney is described as consisting of two portions, the cortical and the medullary or tubular, as seen in *Fig.* 88, in which 1 is the supra-renal capsule; 2, the vascular portion of the kidney; 3, 3, tubular portion grouped into cones; 4, 4, papillæ projecting into calices; 5, 5, 5, the three infundibula; 6, the pelvis; 7, the ureter. (Wilson.) From which it appears that the cortical substance is the external portion, and the tubular is

Fig. 88.

Section of the kidney.

grouped into cones, the base of each cone being outward, and the point toward the pelvis of the kidney. The cortical substance, however, envelops the cones nearly to their points. It is of a red color, and is the seat of the secreting action. The urine, as it arises, passes along the fine convergent vessels, the uriniferous tubes, and these, coalescing as they approach the points of the cones, give origin to what are termed the ducts of Bellini. From these the secretion passes into the calices, thence into the pelvis, and so along the ureter into the bladder. In the cortical substance there are large numbers of dark points, the Malpighian bodies. Their diameter is about $\frac{1}{100}$ of an inch.

Mr. Bowman has demonstrated that the minute structure of the cortical portion is as follows: The uriniferous tubes, as they approach it, undergo bifurcation in such a way that the branches continually arising have, for the most part, a diameter of about $\frac{1}{480}$ of an inch. As they enter it they are contorted, and at their ends present small capsules or flask-shaped sacs. Each of the capsules is entered by a twig of the renal artery, which at once divides into loop-like branches constituting a tuft, and which delivers the blood to a vein originating in the interior of each tuft. These structures are known as the Malpighian corpuscles. The vein and artery pass out of the corpuscles usually at the same point; the vein, however, instead of delivering its blood at once to the renal vein, forms a plexus on the sides of a uriniferous tube, in this simulating the mechanism of the portal vein, which begins in a capillary system and ends in one. It is supposed that the exudation of the water of the urine takes place in the Malpighian body, and the secretion of the solid portions from the cells which cover the uriniferous tubes.

Structure of the Malpighian corpuscles.

The chief feature of this structure is, therefore, that in a sac formed upon a uriniferous tube, a tuft of capillaries, the walls of which are of extreme tenuity, permits water to escape from the blood supplied by the emulgent artery. The blood, thus concentrated by loss of its water, passes into the veinlets which originate in the interior of the tuft; these, converging into a little trunk, less in diameter than the twig of the emulgent artery, escape along with that vessel from the capsule; but, instead of discharging its contents into the renal vein, it ramifies in a plexus on the walls of a uriniferous tube, thus affording a miniature representation of the portal vein, beginning in a capillary system and ending in one. From the plexus the commencing capillaries of the renal veins arise.

Circulation of the blood in the kidney.

Some anatomists suppose that the Malpighian capsule is not, in reality, a flask-like expansion of the uriniferous tube, but that the tube, dilating, folds over the blood capillaries, and so receives them. However that may be, they form a loose ball in its interior, fastened to it only by the arterial twigs and its corresponding and juxtaposed vein.

Fig. 89.

Half diagram of human Malpighian corpuscle, magnified 300 diameters.

The foregoing description is illustrated by the annexed figures, *Fig.* 89 being half diagrammatic, from Kolliker. 1, a Malpighian capsule, A, with the tubulus uriniferus, B, C, springing from it; *a*, membrane of Malpighian body, continuous at *b* with the membrana propria of convoluted tubule; *c*, epithelium of Malpighian corpuscle; *d*, that of tubule; *e*, detached epithelium; *f*, vas afferens; *g*, vas efferens; *h*, glomerulus Malpighianus: 2, three epithelial cells from convoluted tubule, magnified 350 diameters—one with oil drops.

Fig. 90, Glomerulus, or tuft of blood-vessels from the innermost part of the cortex of the kidney of the horse: *a*, arteria interlobularis; *af*, vas afferens; *m m*, glomerulus; *ef*, vas efferens; *b*, divisions of arteriola recta in the medullary substance.

Fig. 90.

Glomerulus from the horse, magnified 70 diameters.

Fig. 91 shows the ciliated epithelium of the uriniferous tube in the frog: *a*, cavity of the uriniferous tube; *b*, its epithelium; *b′*, ciliated portion thereof; *b″*, detached ciliated epithelial cell; *c*, basement membrane of the tube; *c′*, that of the capsule; *m*, capillaries of the tuft; *t*, adjacent uriniferous tube.

Fig. 91.

Cilia on uriniferous tube of frog.

Mr. Bowman's explanation of the Malpighian circulation is represented in *Fig.* 92. *a*, branch of renal artery; *af*, afferent vessels; *m*, *m*, Malpighian tufts; *ef*, *ef*, efferent vessels; *p*,

Fig. 92.

...m of Malpighian circulation.

their plexus upon the uriniferous tube; *st*, straight tube; *ct*, convoluted tube.

I am indebted to Dr. Isaacs for the following instructive figures and descriptions from his paper read before the Academy of Medicine. His method of examination of the minute mechanism of the kidney, by rendering small portions of it transparent, greatly facilitates these researches. Dr. Isaacs's in...gations are entirely confirmatory of Bowman's views, so far as structure ...ncerned. *Fig.* 93 is a view obtained ...gitating scrapings of the kidney of a

Fig. 93.

Malpighian tuft with uriniferous tube, magnified 75 diameters.

Fig. 94.

Ruptured Malpighian coil of the deer, magnified 80 diameters.

Fig. 95.

Nuclea'ed cells c 1 coil, magnified 80 diameters.

sheep (which had previously been injected with chrome yellow and sulphuric ether) in a test-tube with water. The portion on the left shows the tuft alone, that on the right its reception in the uriniferous capsule.

Fig. 94 shows the artery, filled with injection, and the Malpighian coil or tuft ruptured in the capsule. The injected material lies in broken portions. Fragments of the in-

jected vessels of the coil are seen passing down the tube. From the kidney of the deer.

A difference of opinion prevails among anatomists as to the existence of nucleated cells upon the Malpighian tuft or coil in the case of the higher animals. This question is finally settled by Dr. Isaacs in the following manner. An ethereal or watery-colored solution is injected into the ureter, so as to distend the tubes, burst, and throw off the capsule. The cells can then be seen upon the naked tuft or coil. *Fig.* 95 shows the Malpighian body and uriniferous tube of the kidney of the black bear. The artery had been first partially filled with injection, which had broken the coil in pieces. The injection from the ureter ruptured the capsule, which is seen in shreds. Nucleated cells are seen on the naked coil or tuft. In the upper part of the figure, to the left, is a broken tuft, on the right of which the ruptured capsule is perceived, and nucleated cells upon the uncovered tuft. In the upper part of the figure, to the right, are the fragments of a Malpighian tuft, with nucleated cells adhering to it. The capsule had been torn off with a fine needle. All the above drawings were made under the microscope.

The urine, its properties and quantity.

The urine of man is a clear, amber-yellow liquid, the average specific gravity of which may be taken at 1.020, giving an acid reaction when first voided, but gradually becoming alkaline and turbid. Its composition varies greatly with preceding states of the system, and the nature and quantity of the food. It amounts, in the course of a day, to from 20 to 50 ounces; this, however, depending on the quantity of water that has been taken, and on the activity of the skin. Its solid ingredients vary from 20 to 70 parts in 1000 of the urine, the leading substances being urea, uric acid, lactic acid, vesical mucus, epithelial debris, extractive, and salts.

The urine of carnivorous differs from that of herbivorous animals, the latter being turbid, and having an alkaline reaction; that of the former transparent, pale yellow, and acid.

From Winter's experiments, it appears that for every thousand parts of his weight a man discharges 25.9 parts of urine per diem, the maximum being 46.8, the minimum 14.0. A child, reduced to the same standard, discharges 47.4 parts; but a cat, fed on a flesh diet, 91.036. The quantity of water thus removed depends, to a very great extent, on the existing conditions of the system; sometimes it is far less than would answer to the amount that has been taken; sometimes, on the contrary, more. The solid material likewise exhibits very great fluctuations.

Origin of the other urine constituents.

Viewed as a group, the constituents of the urine are evidently the oxidized residues of the system, which, unable, from their not possessing the vaporous or gaseous form, to escape through the lungs, are, from their solubility in water, readily removed

by the kidneys. The urea and uric acid are derived from muscular decay; perhaps, of the two, the uric acid first arises, and is subsequently converted into urea; this is not, however, its exclusive source, since the quantity of urea increases by the use of highly nitrogenized food. The mucus and epithelial debris are derived from the mucous membrane lining the interior of the urinary apparatus. Of the salts, there are two of unusual interest, the sulphates and phosphates, each having, like the urea, a double origin, the food and tissue decay. Leaving out of consideration that part which has been supplied by the food, we recognize in the sulphates the final disposal of that sulphur which was once secreted by the liver, and subsequently reabsorbed. In the phosphates we recognize the oxidation of the free phosphorus of the nervous vesicles during their period of activity. That portion of the solid constituents of the urine which is due to decay or retrograde metamorphosis is shown when an animal is exclusively fed on sugar.

Constitution of urine.

Composition of Urine. (From Berzelius.)

Water	933.00
Urea	30.10
Uric acid	1.00
Lactic acid, lactate of ammonia, and extractive	17.14
Mucus	00.32
Sulphate of potash	3.71
Sulphate of soda	3.16
Phosphate of soda	2.94
Bi-phosphate of ammonia	1.65
Chloride of sodium	4.45
Muriate of ammonia	1.50
Phosphates of lime and magnesia	1.00
Silica	0.03
	1000.00

The composition of urine is not only disturbed by variations in the amount of its normal ingredients, but likewise, in morbid states, by the appearance of unusual ones. Among these may be more particularly mentioned sugar, albumen, blood, bile, pus, fat. The presence of such abnormal ingredients is determined by chemical tests or microscopic observations.

Since the urinary apparatus is the sewer of the system, tables, like the preceding, which purport to set forth the composition of its excretion, can only be received as general illustrations. In the urine must occur whatever materials have been generated in the complicated disintegration of the economy, and whatever useless substances have found their way in through the absorbents by reason of their solubility in water.

Variability of its constitution.

Respecting the substances thus occurring, either normally or unusually, in the urine, the following are observations of interest:

The quantity of urea excreted depends more upon the nature of the

Variations in the quantity of urea.

food than upon any other condition. It reaches its maximum under an absolute animal diet, and its minimum under a non-nitrogenized one. It still appears during fasting, and about to the same extent as during a non-nitrogenized diet. Its sources, therefore, are partly the waste of the tissues and partly the food.

By several observers, urea has been detected in the blood under ordinary circumstances. After extirpation of the kidneys it has been repeatedly recognized in that of the lower animals. It is removed with such rapidity by the kidneys that its quantity is probably never permitted to exceed a fiftieth of one per cent. of the circulating blood. Its origin has generally been attributed to the waste of muscular tissue, though it has not yet been detected in muscle juice; but then it should be remembered that creatine and inosic acid may produce it during their descending metamorphosis. Under this view, the seat of its production would be the blood itself, a conclusion which is enforced by the circumstance that caffeine also increases its amount.

Origin of the urea.

In his inaugural dissertation, entitled, "Is muscular Motion the Cause of the Production of Urea?" Dr. John C. Draper, by experiments on the urine of persons in different conditions of motion and rest, and by an examination of the diurnal and nocturnal variations in the amount of urea voided, compared with an invariable standard, gives reasons for concluding that the differences in the amount of urea excreted are almost entirely attributable to the influence of the food, an individual in such a state of comparative rest as is observed during treatment for a fractured leg not excreting by any means so much less urea as might have been anticipated when compared with another individual who walked thirteen miles at the rate of four and a half miles an hour.

But, on examining the influence of food, it appears to be well marked. The greatest amount of urea is excreted within a few hours after dinner. Another maximum also occurs just after breakfast; but during the eight night hours far less is excreted than during the same period in the afternoon.

The ingestion of food thus exercising so rapid and marked an influence on the quantity of urea, he refers to it as the cause of the increased excretion of that substance during the course of the day rather than to the increased motion of exercise then indulged in; and in view of this conclusion, it becomes probable that the nitrogen of the wasting muscular tissues escapes, not under the form of urea through the kidneys, but through the skin, or perhaps even as free nitrogen from the lungs.

Variations of the sulphates.

Of the variations of the sulphates, it may be observed that the average diurnal excretion of sulphuric acid per thousand parts of man being 0.050 of a part, an increase is observed during digestion, a diminution occurring during the night, the minimum being

reached in the forenoon. Exercise to a moderate degree does not seem to influence it, though that of a more violent kind, and also mental excitement, do. Fasting for one day does not diminish it. Copious drafts of water increase it, but it subsequently declines. The administration of sulphur, and of the sulphates of potash, soda, and magnesia, also increases it, the latter salts being removed from the system through the kidneys.

The quantity of extractive matter excreted by children is much more than that excreted by adults, when estimated, as all such observations ought to be, by reduction to a common standard. Thus Scherer found that for every thousand parts of weight a child excreted 0.346 of a part of extractive per diem, but an adult, for each thousand parts of weight, excreted 0.156 of a part, which is less than half as much.

Quantity of extractive in urine.

The quantity of chlorine in the urine, as chlorides of sodium and potassium, undergoes many variations. Hegar shows that it is at a maximum in the afternoon, at a minimum in the night, and rising toward morning. Its quantity is increased after taking water, and then diminishes. Muscular exercise also increases it. It is interesting to remark that, in inflammatory conditions accompanied by copious exudations, the chlorides in the urine are so much diminished that that secretion in its fresh state will yield no precipitate with nitrate of silver. In 80 cases of pneumonia observed by Redtenbacher, the acidified urine did not become turbid with nitrate of silver, but as the inflammatory action subsided the chlorides reappeared.

Variations in the chloride of sodium.

Of medicaments and other unusual substances introduced into the organism, those which are soluble in water, and have little affinity for the constituent matters of the body, are removed in the urine. In this list are found a great number of salts which escape in this manner without undergoing any change; such, for example, as carbonate of potash, nitrate of potash, bromide of sodium. Other substances undergo change previously to their elimination, as, for instance, the alkaline sulphides, which become oxidized, and are then finally removed as alkaline sulphates. Dr. Bence Jones has satisfactorily shown that, when ammonia is taken, it is removed as nitric acid in the urine. Under the administration of the neutral alkaline salts of vegetable acids, alkaline carbonates in excess appear, owing to the oxidation of their acid in the blood. That this is the true seat of the oxidation, and that it takes place with great rapidity, is demonstrated by the injection of such salts into the jugular vein, which very soon are found as carbonates in the urine.

Escape of unusual salts in the urine.

When oxalate of lime is introduced into the stomach, it does not make its appearance in the urine, perhaps because of its insolubility present-

ing a difficulty to its absorption. In the case of some animals it occurs naturally in the excrement. When, in man, it is found in the urine, its occurrence may be often traced to a disturbance of the respiratory function, or to abnormal metamorphosis occurring in the blood. Under such circumstances it presents itself in convalescence from typhus. That it can arise from such metamorphosis is proved by the circumstance that it is found in the urine after the injection of urates into the veins. When the kidneys act vicariously for the lungs, there thus appears to be a tendency to the removal of carbon under the form of oxalic instead of carbonic acid.

Production of oxalic acid in disturbed respiration.

Hippuric acid may arise in the organism from the metamorphosis of benzoic and cinnamic acids, the administration of these substances being followed by its excretion in the urine. If any thing was necessary to prove that the seat of its origin is the blood, its discovery therein, in the case of the ox, by Verdeil and Dollfass would be sufficient. Its general occurrence in the urine of graminivorous animals, and its absence in that of the carnivora, indicate that its normal production is connected with the nature of the food. However, among some of the lower animals it is still excreted while they are in a state of starvation, and it has been recognized in the urine of diabetic patients under a strict animal diet.

Occurrence of hippuric acid.

After the injection of alkaline lactates into the jugular, the urine becomes alkaline in the course of a quarter of an hour. If they have been taken into the stomach, in about double that time. The passage of other salts is sometimes even more rapid; thus the ferrocyanide of potassium has been detected in the urine in less than two minutes.

Disappearance of alkaline lactates from the blood.

The excess of protein bodies absorbed from the digestive canal, and unnecessary for the repair of the system, is removed as urea and uric acid; and, in like manner, the sulphur and phosphorus introduced by those bodies are, after oxidation, discharged as sulphates and phosphates. Under the use of a strictly animal diet, the urine resembles that of carnivorous animals in color, acid reaction, and freedom from lactic and hippuric acids.

Excess of protein bodies removed.

The phosphate of lime often almost totally disappears during pregnancy, and fractures unite at that period with difficulty.

Disappearance of phosphate of lime.

Many circumstances regulate the length of time that extraneous substances will remain in the system; thus it sometimes occurs that, after the administration of alkaline salts of organic acids, the alkalinity of the urine will disappear in the course of half a day, while on other occasions it will continue for several days. The period also varies very much with different individuals.

Period that extraneous substances may remain in the system.

When the substance administered is of such a chemical nature that it can unite with any tissue, it may remain in the system for a very long time.

The anatomical construction of the Malpighian bodies has led physiologists to infer that there are two distinct stages in the secretion of urine. These have already been pointed out in the remark that the Malpighian bodies separate water from the blood, but that the solid ingredients are secreted from that delicate plexus of vessels which covers the walls of the urinary tubes. Before accepting this opinion, we may, however, observe, that the chief solid constituents of the urine, as urea, uric acid, sulphates, and phosphates, preexist in the blood, and are all soluble in water. It is not to be supposed that the water which oozes through the delicate walls of the Malpighian tufts should leave such substances behind it. That the loss of water actually takes place in the tuft circulation appears to be proved by the fact that the vessel emerging from the tuft is less than the one entering it; the volume of blood is less by the amount of abstracted water.

Manner of secretion of the urine salts by filtration.

We must, moreover, take care that we are not deceived by a name. The vessel emerging from the tufts may be conveniently enough called a *vein*, but is there any proof that such is its physiological attitude? There is no reason to believe that the blood has lost its arterial character while it has been in the tuft. At the most, it can only have lost the elements of urine. It is not until it is distributed in the plexus on the walls of the uriniferous tubes that it really gains the venous character, and then through nourishing those vessels, and particularly the cells of their interior.

The arterial quality retained in the tufts.

These considerations therefore lead me to the suggestion that the inorganic bodies, as urea, uric acid, sulphates, and phosphates, which may all be regarded as products of final oxidation, pass out with the water in which they are dissolved while the blood is yet circulating in the Malpighian tuft. The loss of velocity in the current by the arterial twig breaking up into so many vessels must, as Mr. Bowman states, greatly favor this transudation, as does also the pressure that must arise from the blood having to pass through a narrow channel of exit, and still more through another capillary system just beyond. It was arterial blood that entered the tuft, and it is arterial blood that emerges, to be then directed upon the walls of the uriniferous tubes.

And now the question may arise, What is the object of this second capillary circulation? Though the statement is often made that the constituents of the urine are the results of oxidation, it is very far from being strictly true. The analysis of urine shows that a very large proportion of them, classed as extractive, are really combustible bodies, and not far advanced in their retrograde meta-

The cells remove unoxidized substances.

morphosis. They retain still, as it were, the traces of organization; they belong rather to the hydrocarbon family than to the nitrogenized. It may be that, for the removal of these, cell action is necessary.

Mode of removal of the liquid from the Malpighian sac.

Whatever importance may be attached to such a suggestion, it is very clear that, notwithstanding the extreme thinness of the walls of the tuft vessels, the relaxation in the speed of the blood current through them, and the pressure brought to bear upon them, that water could not be separated by oozing through them unless there was an additional provision. The sac into which the exudation is to take place is already full, and it may be questioned whether ciliary motion in the uriniferous tubes would exert a sufficient exhaustion to relieve the interior of the capsule from pressure; but the introduction of a liquid of a different nature into the uriniferous tube may call at once into operation the principle described at page 131 as acting in the capillary circulation of the blood, and thus the contents of the Malpighian sac are drawn forward into the uriniferous tube, just in the same manner that water is drawn from the inside of a bladder through the pores thereof by alcohol on the outside.

THE MAMMARY GLANDS.

Description of the mammary gland.

The mammary glands are situated on various portions of the abdominal and thoracic surfaces of animals of the class mammalia. In the higher members of this class they present the appearance of racemose glands, rudimentary in the males, but well developed in the adult females, especially after parturition. They separate from the blood the white secretion, milk.

Its comparative anatomy.

In the ornithorynchus the mammary gland consists of an obtuse cone of cœcal follicles, ending upon an areolar surface. There is no nipple. The milk is expelled, both in these and the marsupials, by direct muscular pressure. In cetaceans the nipple is included in a cleft of the integument, but in the higher mammalia it projects, so that, being received into the mouth of the young, and suction being made, the pressure of the air takes effect upon the surface of the gland and expels the milk.

In different cases the number of mammæ differs. In the human species there are but two, placed upon the thoracic surface, and from their position favoring the care and nursing of the child. Among other animals the number seems to have a relation to the number of young brought forth at a birth, there usually being a pair for each one. Many exceptions to this rule, however, occur.

Its structure.

The mammary gland corresponds in anatomical structure to the parotid and pancreas. It consists of 15 or 20 lobes, each from ½ to 1 inch in width; these are composed of lobules, and these, again, of cœcal vesicles. The excretory ducts are lined with tesselated

thelium. The ducts converge toward the nipple, opening upon it by or 15 apertures, and in their course dilating into ampullæ, of small pacity in women, but in the cow capable of holding a quart.

Fig. 96.

velopment of the mammary gland.

Its development.

As regards its development, the mammary gland originates in the fourth or fifth month as a papillary projection of the mucous layer of the epidermis, as shown in *Fig.* 96, in which 1 is the rudimentary gland in the male embryo of five months, *a* being the horny, *b*, mucous layer of the epidermis; *c*, process of the latter, the rudiment of the gland; *d*, fibrous membrane round it. At 2 is the lacteal gland of a female embryo of seven months, seen from above: *a*, central substance of the gland; *b*, *c*, budding outgrowths, the rudiments of the gland lobes. (Kolliker.)

Fig. 97, vertical section of the human mammary gland: *a*, *a*, its pectoral surface; *b*, *b*, skin on surface of the gland; *c*, skin of nipple; *d*, lobules and lobes of gland; *e*, lactiferous tubes passing from the lobules to the nipple.

Fig. 97.

tion of the human mammary gland.

As pregnancy advances, the cells of the gland begin to contain fat, in a manner not unlike that which is remarked in the cells of the sebaceous follicles of the skin. When the gland becomes active after parturition, it is stated that the first-formed milk-cells break up in the lactiferous ducts into milk globules, their membrane and nucleus disappearing. The milk globules are minute particles, varying in their diameter from the $\frac{1}{8000}$ to the $\frac{1}{13000}$ of an inch. They consist of oily material inclosed in an envelope, as is shown by the fact that, ough they will resist for a short time the action of sulphuric ether, they are finally dissolved by that substance. Besides these milk globules, there are other exceedingly minute fat particles present. The milk which is first secreted after delivery contains corpuscles of considerable size, and of a granulated appearance, as seen in the photograph, *Fig.* 98. They are called colostrum corpuscles. They are soluble in ether, and therefore contain fat. There is reason to suppose that all fat globules of the milk are inclosed in cyst-like pellicles of casein.

Milk globules.

Fig. 98.


 with colostral corpuscles.

Colostrum.

In the chapter on food (Chapter II.), a general description of the charer and constitution of milk has been given, together with its physio-

Properties of milk.

logical relations in nutrition. It may now be added that fresh milk presents an alkaline reaction, which continues longer in the milk of women than in that of cows. Left to itself, and the more quickly the warmer the air, milk turns sour through the production of lactic acid, the casein undergoing coagulation. That the oil globules just spoken of are coated with a film of a coagulated protein body appears from the circumstance that it may be dissolved by acetic acid, and the included butter is then set free.

Analysis of milk.

One of the simplest methods for the analysis of milk consists in coagulating it at a temperature of 212° with pulverized gypsum; the mass, being then evaporated to dryness, is pulverized, the butter being extracted by ether, and the sugar and soluble salts by hot alcohol. The amount of the soluble salts thus obtained may be determined by incineration; and since their amount is to that of the insoluble salts as 5 to 7, an approximate determination of the latter may be made, and thereby the weight of the sugar and casein corrected. This is the method of Haidlen.

Relation of colostrum and milk.

It would appear, from examinations that have been made of the secretion of the mammary gland previous to parturition, that it contains albumen in the place of casein, the casein gradually appearing as the period of parturition approaches, but not reaching its maximum until a few days after that event. Colostral milk differs essentially from the subsequent ordinary secretion, as the following table shows:

Constitution of Colostrum and Milk. (*From Simon.*)

	Colostrum.	Milk.
Water	828.00	887.60
Fat	50.00	25.30
Casein	40.00	34.30
Sugar of milk	70.00	48.20
Ash	3.10	2.30
Loss	8.90	2.30
	1000.00	1000.00

The specimens here presented were obtained from the same individual; and from the table it appears that the colostrum contains a much larger proportion of solid material than the milk. The quantity of fat is nearly double; the quantity of sugar is likewise much greater, but the relative quantity of casein is less, this being in accordance with the statement that the production of that substance approaches gradually to a maximum which is not attained till a few days after parturition.

Variability in its composition.

The composition of milk varies with many circumstances. Thus, among cows, it is well known that there are certain breeds which yield a milk in which butter predominates; in others, a milk in which there is an excess of casein. It is in reference to this that such are, among agricultural people, often described as good butter

ws, or good cheese cows, as the case may be. Such variations are ewise often popularly referred to peculiarities in the color of these anils; and, indeed, there is a general impression of the same kind as reects the milk of women, that that of fair women is inferior to that of unettes. L'Heritier, who has examined into this matter, selected two nales of the same age, 22 years, and caused them to adopt the same et and the same mode of life. The one was a blonde, the other a brutte. The following table exhibits the most marked of his results:

Milk of Women of different Temperaments. (From L'Heritier.)

	The Blonde.	The Brunette.
Water	892.00	853.30
Butter	35.50	54.80
Casein	10.00	16.20
Sugar of milk	58.50	71.20
Salts	4.00	4.50
	1000.00	1000.00

ie average of the various analyses he made shows the same general relt, though not so strikingly, the number being for the solid constituts, in the case of the blonde, 120, and for that of the brunette, 134.

As would be expected, the constitution of the milk varies greatly with diet. Simon found that in the case of a very poor woman, o had been almost deprived of the necessaries of life, the antity of solid material was only 8.6 per cent. On giving her a nutrius meat diet it rose to 11.9 per cent. Being again reduced, by cirnstances, to the utmost destitution, the solid residue sank to 9.8 per it.; and on once more being supplied with a nutritious meat diet, the rcentage rose to 12.6. These results illustrate in a striking manner, will be presently seen, the function of the mammary gland. Simon o found, in this particular case, that the relative quantities of casein l sugar do not greatly vary with these extreme dietary variations, but it the absolute quantity of butter does. On the two occans of starvation, it was as low as 8 parts in 1000 of milk, l on the two of full nutritious diet, it rose to 34 and 37 pectively. From this it seems to follow that while the amount of tter in milk is determined by the quantity and quality of the food, the ounts of casein and sugar are, to a considerable degree, independent reof, and hence I believe their origin is to be attributed to changes ting place in the system, and that these substances are more immedily furnished from metamorphoses of its structures.

Influence of diet on milk.

Origin of the casein and of the butter.

The casein and the sugar are reciprocally related to each other, the antity of casein steadily increasing from the time of parition until a fixed proportion is attained. At parturition quantity of sugar is at its maximum, a gradual decline n occurring until its proportion likewise becomes nearly constant.

Relative quantity of casein and sugar.

Saline substances administered by the stomach or rectum do not always appear in the milk; thus the ferrocyanide of potassium, which may be quickly detected in the urine, can not be found in the milk. It is curious, that when iodide of potassium has been administered to the mother, in doses, for example, of three grains thrice a day, it can be readily detected in the urine of the infant by the usual test of starch and nitric acid.

Extraneous salts in milk.

The diurnal quantity of milk yielded by the human female has been estimated at from 32 to 64 ounces. This estimate is made by determining the weight of the infant before and after suckling. Although a certain proportion is present in the gland, the secretion appears to take place for the most part with great rapidity. On the application of the infant the blood flows suddenly, and the milk pours into the ducts, constituting what is termed the draft.

Diurnal quantity of milk.

We now enter on a consideration of the function of the mammary gland, with a view of determining whether it acts in virtue of its special construction, whether it fabricates in itself, by the agency of cells, the proximate constituents of milk, or whether it merely strains them from the blood in which they pre-exist.

Mode of action of the mammary gland.

Due weight should here be given to the fact that, unlike the excretions of the lungs, the kidneys, or even the liver, the milk contains a very large percentage of histogenetic or formative bodies. Its casein can not be considered as in the career of retrograde transformation, since in the body of the infant it is presently changed into albumen. Such a fact might even lead us to suspect that we should detect some essential structural and functional differences between the mammæ and other glands.

The influence of special structure is, however, disposed of by the numerous well-authenticated cases now on record, in which portions of the skin, or the stomach, the navel, intestines, the axilla, and glands in the groin have assumed a vicarious action, and secreted milk; and though it has been said of the latter instance that it may be nothing more than an obscure manifestation of an attempt in the human species at a repetition of the mammary gland in a region near which it is normally present in the lower mammals, such a remark has no application in the other cases. We may therefore infer that the proximate constituents of the milk are not manufactured by reason of any special structure of the gland which secretes them, since other structures can assume a vicarious action.

Influence of special structure.

This therefore narrows our inquiry down to the point, Does the mammary gland merely filter off from the blood substances already existing in it, or, those substances not so pre-existing, are they made in this organ by cells?

Of the proximate elements of milk, many, such as the entire group

of its salts, are acknowledged on all hands to pre-exist in the blood; and these, constituting about $\frac{1}{25}$ of its solid ingredients, must be admitted to pass into the secretion by strainage only. Of the other solid ingredients, the fat, which constitutes about one fourth, also exists in the blood, being derived by lacteal absorption from the food.

The salts of milk exist in the blood.

Do milk-giving animals, then, find in their ordinary diet a sufficient quantity of oleaginous material to supply the drain established through the mammary gland, and the calorifacient demand, supposing none to be made in the system? The researches of Dumas have definitely settled this question. Of these the following is an abridgment:

The hydrocarbons pre-exist in the food.

Fat in Articles of Forage.

Indian corn	8.75 per cent.
Rice	1.00 " "
Oats	3.30 " "
Rye	1.75 " "
Wheat	2.10 " "
Dry hay	2.00 " "
Clover in flower	4.00 " "
Wheat straw	3.20 " "
Oat straw	5.10 " "
Beet root	0.05 " "
Potatoes	0.08 " "

A cow in good condition, eating 100 pounds of dry hay, will furnish 21 quarts of milk, from which there can be obtained 1½ pounds of butter. If this butter was obtained exclusively from the food, and none made in the system, we ought to find in the 100 pounds of dry hay 1½ pounds of fatty matter; but sulphuric ether can remove from such hay 2 pounds, and in several specimens of clover cut in flower, M. Boussingault found the proportion as high as 4 per cent. We may therefore affirm, relying on the universal experience of farmers, that the hay eaten by a milch cow contains more fat matter than the milk which she yields. Thus far, therefore, we are not authorized to regard the animal as capable of producing the butter found in its milk, but, on the contrary, we may be led to suppose that the whole of it is taken from the food.

Quantity of fat in forage.

In a physiological point of view, a single experiment of this kind is insufficient. Errors may arise in comparing together hay taken by chance, and the produce of milk taken by chance. It would doubtless be far better to establish a direct experiment, giving the proportion of butter, determined by analysis, relatively to the proportion of fat matter consumed by a cow. This experiment has been made on such a scale and with so much care as to be very convincing. It lasted for a year, and was conducted on 7 milch cows, the milk, drawn twice a day, being

carefully measured. The 7 cows furnished 17,576 quarts of milk; its weight was 36,382 pounds. Being analyzed from time to time, it was found to yield 3.7 per cent. of butter, completely deprived of water. From this it follows that these 7 cows furnished during the year 1346 pounds of butter.

During this time they ate 30 pounds of hay, clover, and grass each day; that is to say, the 7 cows consumed during the year 77,650 lbs.

Now if in 100 pounds of hay there are 1.8 of fat, the 77,650 pounds represent 1378; recollecting, however, the use of clover, which is richer in fat, the amount should rise to more than 2000 pounds. But the butter obtained was only 1346 pounds.

From this experiment, therefore, we gather, that a cow which is giving milk finds much more fat in the fodder she eats than is subsequently yielded in her butter. We may therefore conclude that such an animal extracts from her food most of the fat it contains, and that she either stores it up in her adipose cells, uses it for the production of heat, or converts it into butter.

In the argument, as thus presented by M. Dumas, the question is considered in its quantitative aspect, no allowance being made, however, for the amount of oily material accompanying the fæces, and no estimate offered of the proportion destroyed for the sake of producing heat. It might be that the entire amount of fat escapes in the former of these ways, and that, though a sufficiency occurs in the food, it is not absorbed therefrom into the system.

The identical fat of the food is found in the milk.

There are many facts which show that the identical fat occurring in the food is actually delivered by the mammary gland with many of its quantities unchanged. Thus, if by chance cows should eat the tender shoots of pine-trees, or wild onions, or other strong-smelling herbs, the milk is at once contaminated with the special flavor of their oils. The same, too, takes place when turnips are introduced in their diet. If half the allowance of hay for a cow is replaced by an equivalent quantity of linseed-cake, rich in oil, the cow maintains herself in good condition, but the milk produces a butter more than usually soft, and tainted with a peculiar flavor derived from the linseed oil.

Sufficient quantity of fat in the blood.

To the preceding facts it is unnecessary to add any observations in relation to the carnivorous mammals, which obviously find in their prey large quantities of fat. In the chapter on calorifacient digestion, and in that on the functions of the liver, the evidence was presented both as regards the reception of oily material from the food, and likewise its fabrication in the system. From these sources conjointly it may therefore be plainly seen that fats of various kinds must always exist in the blood. A simple arithmetical computation,

founded on the data furnished by the tables of the constitution of blood and of milk respectively, will show that there is at any moment a sufficient supply of fatty matters in the blood to furnish two thirds of the diurnal amount of milk. It does not seem, therefore, philosophical, under these circumstances, to impute to the mammary gland a power of forming butter. It doubtless obtains that substance directly from the blood; and it may be that those bodies which are conceived of as cells, and which are supposed to arise in the lobules of the gland in successive broods, which run a rapid living career, coming into existence, reaching maturity, dying and deliquescing with incredible rapidity, are, in reality, nothing more than oil globules which have coated themselves over with a cyst of coagulated casein, as in Ascherson's experiment, or just as they become coated with a similar film immediately on passing from the intestine into the lacteal vessels; and this, accordingly, is the opinion I entertain of their nature.

Next of the casein. There has been much controversy among chemists respecting the existence of casein as a normal ingredient in the blood. Theoretically there does not appear any solid reason for denying that it may be one of those constituents, considering the analogy of constitution which it shows with albumen. The evidence is much more distinct and positive in the case of puerperal blood, and is greatly strengthened by the recognized tendency to the occurrence of kiestine in the urine during gestation. This substance, to which much attention has of late been devoted, makes its appearance in such urine as a pellicle or membrane, which gradually increases in thickness. It is not commonly seen before 30 hours after the urine is passed, nor later than the eighth day. Though sometimes appearing at an earlier period of gestation, it is more frequent in the seventh, eighth, or ninth months. The fact is not without significance for our present purpose, that it may reappear in the urine after parturition if any thing occurs to check the secretion of milk. Moreover, Prout noticed it in the urine of a delicate child which was fed chiefly on milk. An examination of it shows that kiestine is composed of casein, a butyric fat, and the phosphate of magnesia. Such a constitution betrays at once its relation to the secretion of the mammary gland.

Reasons for inferring that casein exists in blood.

Kiestine.

Lehmann, who inclines to the belief that kiestine is nothing else but the formation of crystals of triple phosphate and fungoid and confervoid growths, which take place when the urine becomes alkaline, admits that, unless it has been the basic albuminate of soda which has been mistaken for it, casein does occasionally occur in the urine. From the acknowledged fact that the acid interstitial juice of muscle fibre contains casein, there can not be any doubt, I think, that that substance must pre-exist in the blood.

The occurrence of casein under the form of kiestine in the urine, in quantity increasing as gestation advances, indicates therefore that the system is assuming a propensity for the generation of this substance from its albumenoid compounds; and since, in cases of starvation, the percentage of casein in the milk does not seem to be materially affected, we are to attribute its immediate source to the system rather than to the food. In this respect it differs from the oily constituent, butter, the percentage amount of which is instantly affected by variations in the nature and quantity of the food. It would seem, indeed, that, from the same plastic ingredient, albumen, the soft tissues of both mother and infant are fabricated, with this difference, that in the latter case the temporary condition of casein is intermediately assumed. We have already remarked on the identity of constitution of albumen, casein, and fibrin, so far as their carbon, hydrogen, nitrogen, and oxygen are concerned; and, indeed, these compounds differ far less in their physical characters from one another than albumen in its coagulated and uncoagulated state; yet that difference in physical quality may be readily brought about by so trifling an agency as rise of temperature through only a few degrees, and is probably dependent upon the different allotropic forms which the carbon constituent is prone to assume. Giving due weight to these various considerations, we shall find reason to conclude that this constituent of the milk, the casein, is directly derived from the system, which can manufacture it at a rate of about 30 grains per hour, this being about one half the quantity of fibrin generated in the same period of time for the support of the muscular tissues. Chemically, the transition from albumen to casein is not to be regarded either as an ascending or declining metamorphosis, but only as the temporary assumption of a state of passage onward to the condition of fibrin.

With respect to the constitution of casein there is considerable doubt.

Complex nature of casein.

The substance commonly passing under this title seems to consist of at least two different bodies; at all events, it may be separated into two parts, one containing sulphur, and the other not; moreover, if to milk, which has been perfectly freed from butter, there be added dilute hydrochloric acid, the ordinary precipitate is yielded, but there still remains in solution an analogous body, which does not precipitate until the mixture is boiled. In milk, though much of the casein is held in solution, much also exists in the coagulated state, forming the wall of the milk globules. Its existence under this membranous form may be demonstrated by the action of acetic acid on milk globules under the microscope, and also by shaking new milk with ether, which produces very little change; whereas, if the milk were only an emulsion, the ether should take up the fat and hold it in solution. Now, on the addition of potash or its carbonate to milk before the action of ether, those

substances dissolve the membrane, and then the ether takes up the fat and forms a dimly-clear solution. We may therefore conclude that the substance we designate as casein consists of two ingredients, the protein compound, which exists in a state of solution in milk, and also that which forms the membrane of the fat corpuscles.

Many of the remarks just made respecting the origin of casein are applicable to the saccharine constituent of the milk, the origin of which is not to be attributed so much to the food directly as to the system; for, in starvation, the sugar, like the casein, still continues to form to nearly the normal amount. I think it is probable that its production is due to the liver, and is, in reality, nothing more than an indication of the continued action of that gland, one of the prime functions of which is the generation of saccharine compounds.

Origin of the sugar of milk.

From the data now before us respecting the origin of the different constituents of the milk, the casein, the butter, the sugar, and the salts, we are able to come to a definite conclusion regarding the physiological action of the mammary gland. I have entered on this long disquisition from the important bearing which the decision we arrive at has upon the whole theory of secretion; for if there be a gland in the body in which we should expect to find proofs of formative power, through the agency of cell life or otherwise, in giving rise to products that did not pre-exist in the blood, it is certainly the mammary. But now, as it appears that all the constituents which its secretion contains are found in the blood, we can scarcely suppose that the gland itself does more than merely strain them out; of course, in common with all such structures, it possesses what might aptly be termed an elective filtrating power; thus it permits the exudation of the iodide of potassium from the blood, but refuses a passage to the ferrocyanide. And, finally, the conclusion to which we thus come recalls the remark heretofore made, that the more thoroughly we study the secretions delivered by the various glands, and the more perfectly we identify the sources from which their constituent ingredients have been derived, the more we should be disposed to impute glandular action to the physical process of elective filtration, and the less to the agency of cell life.

The mammary gland acts by filtration.

OF THE SKIN.

The skin is composed of two layers, the epidermis or cuticle, and the derma or cutis. It contains two systems of glands, one for the removal of water, and another for that of oily substances. It also presents subsidiary parts or appendages, such as the nails and hair.

The epidermis, which is the exterior portion of the skin, originates from the cutis. It has a different thickness in different parts; the contrast, in this respect, being very well shown upon the

The epidermis: its structure.

soles of the feet and the eyelids. In this respect its use is mechanical. It serves as a protective covering to the parts it envelops, being thick where pressure and hard usage have to be provided for, and thinner where there is a necessity for motion. It consists of an aggregation of nucleated particles adhering together, the deepest being granules, the intermediate more perfect cells, which gradually become flattened scales as they are examined nearer the surface. They undergo constant exuviation, and are as constantly replaced from beneath, the superficial ones becoming dry and horny, thus furnishing a resisting tegument, the operation of which is very well displayed by the action of vesicating agents: a watery discharge from the vessels of the cutis soaks through the lower substance of the cuticle, and raises the dry layers above. The chemical composition of these dry scales is the same as that of nail, hair, horn, and is C_{48}, H_{39}, N_7, O_{18}.

Rete mucosum and its coloring matter.

At one time it was supposed that the rete mucosum, or layer of Malpighi, which is the lowest portion of the cuticle, and therefore resting on the cutis, is a distinct structure. It is, however, merely the most recently-formed portion of the cuticle. The netted appearance it presents originates in the eminences of the papillary structure below. Many of its constituent particles contain coloring matter, especially in the dark races. The pigment seems to be produced by the agency of the sunlight and continued high temperature, though it disappears gradually as the cells containing it approach the surface. It yields a very large percentage of carbon.

The derma: its construction.

Beneath the epidermis is the derma or true skin. It is composed of fibrous tissue, which also serves to connect it with the parts beneath, blood-vessels, lymphatics, and nerves. In its areolar tissue both the white and yellow fibrous elements are found, the proportion of each varying according to the mechanical function the part has to discharge, the yellow predominating where elasticity is required, and the white where a resistance to pressure. The derma also contains organic muscular fibres, to which its property of corrugation, as in cutis anserina, is due. On different parts it is of different thickness, being thinnest where motion has to be provided for. A deposit of fatty material, lodged beneath, gives it a yielding support. Its outer surface presents a papillary structure, which is the instrument of touch. This is more perfectly developed on the inner surface of the palm of the hand and fingers. The furrowed aspect of the cutis arises from this. A farther consideration of the mechanism and functions of the papillæ is deferred to the description of the sense of touch.

The photographic engraving, *Fig.* 99, represents a thin section of the epidermis of the foot of the dog.

The general method of arrangement of the constituent portions of the

Fig. 99.

Epidermis of dog, magnified 20 diameters.

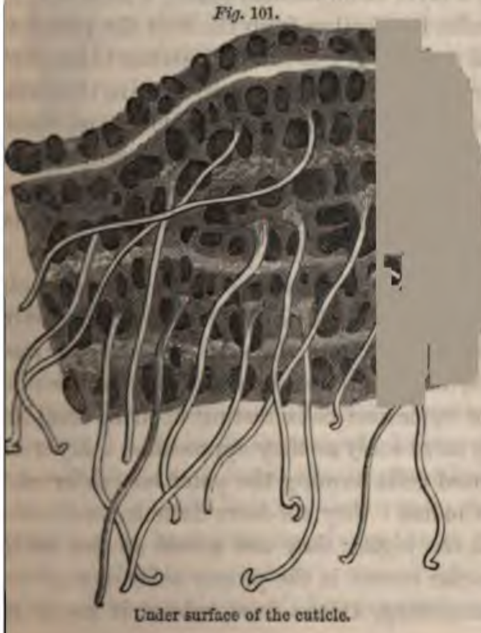
Fig. 100.

Perpendicular section of skin of ear, magnified 10 diameters.

skin may be gathered from the perpendicular section of that of the external auditory meatus in *Fig.* 100. *a*, the derma; *b*, rete mucosum; *c*, horny layer of epiderma; *d*, coil of ceruminous glands; *e*, their excretory ducts; *f*, their apertures; *g*, hair-sacs; *h*, sebaceous glands; *i*, masses of fat. (Kolliker.)

Fig. 101 shows the under surface of the cuticle detached by maceration from the palm, exhibiting double rows of depressions, in which the papillæ have been lodged, with the hard epithelium lining the sudoriparous ducts in their course through the cutis. Some of them are contorted at the end, where they have entered the sweat gland. (Todd and Bowman.)

Fig. 101.



Under surface of the cuticle.

Fig. 102, papillæ of the palm, the cuticle being detached. (Todd and Bowman.)

Fig. 102.

Papillæ of palm, magnified 35 diameters.

Fig. 103, surface of the skin of the palm, showing the ridges, furrows, cross grooves, and orifices of the sweat-ducts. The scaly texture of the cuticle is indicated by the irregular lines on the surface. (Todd and Bowman.)

The nails.

The NAILS constitute one of the appendages of the epiderma. They are horny coverings protecting the extremities of the fingers and the toes. They originate in a fold of the cutis, and become free at their outer extremity. The nail grows from its roots, increasing in length, and simultaneously in thickness. Its rate of growth depends upon the general rate of nutrition. During periods of sickness or abstinence, its growth in both directions is retarded, as is indicated by a mark or impression on its surface, and so the nail becomes a register of the condition of nutrition during the period of its own existence. The thumb nail is said to occupy about 20 weeks in its growth from the root to the extremity; that of the great toe about two years—an estimate which is probably too long.

Fig. 103.

Skin of palm, magnified 20 diameters.

The hair.

THE HAIR.—Each hair originates in a flask-shaped follicle, formed by a depression of the cutis, and lined by a continuation of the cuticle, and, like it, presenting scales on its superficies and round cells beneath. The bottom of the follicle is the place of origin. The hair consists of two portions, the outer or cortical, and the inner or medullary, the proportions of which differ very much in different cases. The surface of the hair presents a layer of imbricated scales, within which, at the lower part, are minute cells, but farther from the root the cells become larger and begin to contain pigment, the coloring matter being distributed unequally, sometimes producing a tubular appearance in the axis.

Fig. 104.

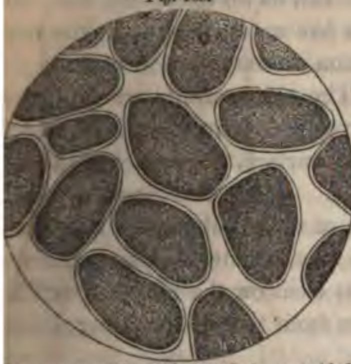
Human hair in section.

The hair grows by constant prolongation from the follicle, its color being due to a peculiar colored oil; and in the black varieties, iron predominates. The diameter of the hairs varies from $\frac{1}{140}$ to $\frac{1}{1500}$ of an inch.

In *Fig.* 104, the structure of the root of a hair and part of its shaft is displayed. Bulb of a small black hair from the scrotum, seen in section: *a*, basement membrane of the follicle; *b*, layer of epidermic cells resting upon it, and becoming more scaly as they approach *c*, a layer of imbricated cells forming the outer lamina or cortex of the hair: they are more flattened and compressed the higher they are traced on the bulb. Within the cortex is the proper substance of the hair, consisting, at the base, where it rests on

he basement membrane, of small angular cells, scarcely larger than their nuclei. At *d* these cells are more bulky, and the bulb consequently thicker: there is also pigment developed in them; above *d* they assume a decidedly fibrous character, and become condensed; *e*, a mass of cells in the axis of the hair, much loaded with pigment. (Todd and Bowman.)

Fig. 105.



Transverse section of human hair, magnified 200 diameters.

Fig. 105 is an engraving of a photograph of a transverse section of human hair from the head. The outer line shows the cortex; in some the pigmentary axis is seen; in most, however, it is absent.

The sudoriparous glands.

The Sudoriparous Glands originate in depressions of the cutis or issues beneath, occurring in some parts, as in the axilla, more numerously than in others. They consist of a tube wound on itself, and sometimes dividing in convoluted branches. The knot thus arising is contained in a cell, the wall of which is copiously supplied with blood-vessels: the duct passes through the superjacent tissues. The tube is formed of a cylinder of basement membrane lined with epithelium. The basement membrane may be considered to be derived from the outer surface of the papillæ, and the epithelium is an external projection of the cuticle. The duct, on its passage outward, loses its basement membrane as it escapes between the papillæ; and it has a spiral or helical aspect, an arrangement probably intended to keep the calibre open. It is estimated that the number of sudoriparous glands is about seven millions, and the total length of their tubing about 28 miles.

Fig. 106.

Sudoriparous gland, magnified 20 diameters.

Fig. 106 is a sudoriparous gland from the palm of the hand: *a*, *a*, knot of tubes with two excretory ducts, *b*, *b*, uniting into a helical canal, which perforates the epidermis at *c*, and opens on its surface at *d*: the gland is imbedded in fat vesicles at *e*, *e*, *e*, *e*. (Wagner.)

The sebaceous glands.

The Sebaceous Glands are distributed in different abundance in various parts, their office being to lubricate the hair, to keep the skin in a flexible condition, and avoid the inconveniences of friction. Their ducts open either into the hair follicles or upon the cuticular surface; the gland consisting of basement membrane lined with epithelium, the cells of which, as they reach maturity, become filled with a sebaceous or oily material. The ear glands of this class secrete a waxy matter.

Such being the construction of the skin, we have next to speak of its action. It discharges a double function: 1st, as an excreting, and, 2d, as an absorbing organ. In this respect it has an analogy with the mucous membrane, which, indeed, is a reflection or continuation of it.

Different kinds of perspiration.

Of the excreting action of the skin. The skin permits water, saline and fatty substances, to escape from it in quantities which differ on different portions of its surface, the nature of the secretions varying to meet local requirements. In the examination which we are now entering upon, we shall speak of these substances and their proportions in a general way, overlooking, for the time, the particular variations. Yet that such variations exist is clear on the most superficial observation. The sweat of the feet differs from that of the general surface, as, again, does that of the arm-pits.

Quantity of water through the cuticle and from the ducts compared.

It has been usual to distinguish the watery transudation into two portions, that which escapes from the perspiratory ducts, and that passing through the surface of the cuticle. It has even been said that the true glandular secretion passing from the ducts is not more than one sixth of the total cutaneous exudation; but this, I believe, is altogether erroneous. When we recall the impermeable nature of the horny and dried scales which constitute the outer portion of the cuticle, and that these are constantly coated over with an oily varnish issuing from the sebaceous glands, we may infer that the cutaneous surface between the mouths of the perspiratory ducts is constructed rather for the hinderance of evaporation than for its promotion; and though the oily matter with which the skin is thus imbued is justly regarded as having for one of its functions the prevention of injury from the admission of external moisture, it must be equally effectual in stopping the escape of water from within. The tardy manner in which water thus escapes is illustrated by the operation of blisters.

Exhalation and perspiration.

Under the form of steam, water continually escapes from the skin. It also, on certain occasions, issues in the liquid state as drops of sweat. To its escape under the form of steam the designation of exhalation or insensible perspiration is given; but if under the form of sweat, that of sensible perspiration.

Experiments to ascertain the amount of water escaping through the skin.

Of Exhalation.—On condensing the vapors which arise from the skin, they are found to consist of water containing a little acetate of ammonia. With the water likewise escapes carbonic acid gas. With a view of ascertaining the weight of the matters thus lost, Seguin inclosed himself in an air-tight bag, the mouth of which was gummed upon his face in such a way as to permit the access of air to the respiratory organs. He then determined the weight of his body and the bag together. After several hours, on reweighing, he ascertained the amount of loss by pulmonary

exhalation. Then, taking off the air-tight bag, he was weighed again, and after another interval once more. The difference between the two last weighings is the amount of the pulmonary and cutaneous exhalation together, and from these data, by a simple arithmetical calculation, the value of each may be determined. By these experiments it appeared that the loss by pulmonary and cutaneous exhalation together is, on an average, eighteen grains per minute, of which seven issue from the lungs and eleven from the skin. The variable action of the skin is, however, well illustrated by the extreme numbers observed, the minimum being eleven grains, and the maximum thirty-two. From the experiments of Valentin, the average of loss through the skin is two pounds and nearly half an ounce a day. Seguin's experiments would make it two pounds and three quarters. It has been shown in Chapter X. that the action of the skin is partly meteorological: the amount of water passing through it depends on the dew-point, the atmospheric temperature, the conductibility and perviousness of the clothing. Whatever physical circumstances promote surface evaporation correspondingly promote the action of the skin. Moreover, this membrane acts vicariously with the kidneys, and this not only as regards the water, but also as regards the solid matter, a large amount of which is thrown off in the course of the day.

Causes of the variable action of the skin.

In all computations of the quantity of water eliminated by the skin, it should not be overlooked that any inclosing barrier or bag must necessarily occasion a complete alteration in the conditions under which the action is occurring. On the whole, it is perhaps most probable that the ratio of the matters expired through the skin and those expired by the lungs is as 9 to 5.

Besides the water secreted by the sudoriparous glands, carbonic acid and nitrogen escape. Their relative proportion is variable, and seems to depend, among other things, upon the nature of the food, the carbonic acid increasing under a vegetable, and the nitrogen under an animal diet. From the experiments of Dr. J. C. Draper, above referred to, it appears that the absolute amount of these gases is influenced by exercise.

Transpiration of gases.

Of Perspiration.—When the atmospheric temperature is high, and more particularly if muscular exertion be resorted to, the quantity of water issuing from the perspiratory ducts is so great that it can not be evaporated. It then exudes as drops of sweat, which become mingled with the oily secretion prepared by the sebaceous glands. From this commingling it is scarcely possible to obtain the sweat, in an uncontaminated condition, suitable for analysis, or even to exclude the detritus of the cuticle itself. In a thousand parts of sweat there are from five to twelve and a half parts of solid material. Thenard,

Ingredients of perspiration.

by resorting to the expedient of wearing for some days a flannel shirt which had been thoroughly washed in distilled water, ascertained, after it had again been washed in distilled water, that it had become imbued with the chloride of sodium, acetic acid, phosphate of soda; phosphate of lime, oxide of iron, and an animal substance. Berzelius found in the sweat of the forehead chloride of sodium, lactic acid, and muriate of ammonia. Besides these, other chemists have found butyric acid, the carbonates and sulphates of potash and soda, and the carbonate of lime. That sweat contains sulphur is proved by keeping a portion of it: when putrefaction ensues, the sulphide of ammonium is disengaged.

Fourcroy first detected urea in perspiration, an observation subsequently confirmed by Landerer and others. That the skin can, under certain circumstances, excrete urea, is proved by the interesting fact that this substance sometimes occurs as a bluish powdery material on the bodies of those who have died from cholera.

Occurrence of formic acid in perspiration.

In the perspiration formic acid also exists, and in certain conditions of disease, as, for instance, intermittent, it occurs in considerable quantity. Its origin may be from lactic acid, which passes through this combination in gradually proceeding to its final destruction into carbonic acid and water. It has been asserted that the increased acidity of rheumatic sweats is due to a concentration from evaporation.

Experiment of Krause.

The sudoriparous glands secrete a portion of fat, as is demonstrated by the experiment of Krause, who removed from the palm of the hand, on which there are no sebaceous glands, loose epithelial scales and fat by means of ether and friction, and then placed upon a square inch of it several thicknesses of filtering paper, which was kept in contact for one night, and properly protected externally. The paper yielded to the action of ether a fatty substance, which contained margarine and oil, in quantity sufficient to make tissue paper translucent.

Secretion of fat and oil from the skin.

But, besides the saline substances thus dissolved in water, the skin, through the action of its sebaceous glands, secretes oleaginous material. The nature of this fatty substance differs on different regions, or according to the purposes to which it is to be applied. Where the ducts of the sebaceous glands open into the hair follicles, the fat is of a liquid or oily nature. Sometimes stearine and margarine, sometimes cholesterine is set free. Before birth, this last substance is the chief constituent of the vernix caseosa, coating the surface of the skin. In this manner, sometimes the saponifiable and sometimes the non-saponifiable fats or lipoids are used.

Double action of the skin.

In the midst of these complex actions a very important principle may be discerned. I have spoken of the double action of the kidney, its mechanism for removing saline solutions, and also

that for combustible material. I have now to present the skin under the same aspect. It is not a mere analogy that exists between the action of these organs; the occurrence of urea and of the salt substances, the names of which have been specified in both secretions, is a fact of the utmost significance. I believe that the sudoriparous glands are the counterparts of the Malpighian bodies, and the sebaceous glands, in their function, are the counterparts of the uriniferous tubes. Indeed, this double action is also distinguished in the case of the mucous membranes, which possess one instrumental arrangement for the transit of saline solutions, and another for that of fats. And since the skin, the mucous membrane, and the great glands connected with it, are all to be regarded as developments of one original tissue, we should expect to discover, even in their concentration or specialization of function, the traces of their original and common property. Development takes place from the general to the special; and hence, in parts which have arisen from the same primordial structure, though they may be charged with the accomplishment of functions which, in appearance, differ essentially, there may be, both in their action and in their construction, the traces of their original identity. It is in this manner that the kidneys, and skin, and mucous membrane, possess the property of acting vicariously for one another. The kidney can discharge water for the skin, or the skin urea for the kidney. The combustible matter, known as extractive in the urine, can be set free under diminished renal action by the sebaceous glands, and the saline solutions, eliminated by the convoluted tubing of the tufts of Malpighi, can be set free by the convoluted tubing of the sudoriparous glands. In connection with the views I am here impressing, I would recall the structural and functional analogy there is between the transuding mechanism of the kidney and the transuding mechanism of the skin. Both are arrangements of thin convoluted tubes, and the same may be remarked as regards the elimination of combustible material, which is probably accomplished by cell action in the uriniferous tubes, and again by cell action in the sebaceous glands.

Absorption by the skin both of gases and liquids.

Besides exercising the functions of exhalation and perspiration, numerous facts demonstrate that the skin exerts an absorbent action. The endermic application of remedial agents establishes this in a satisfactory manner. That water can find access in this way is shown by the assuaging of the thirst which may occur on taking a bath; nor is the amount insignificant, since it may give rise to a considerable increase of weight. Thus lizards, which have been kept in a dry atmosphere, and thereby suffered a diminution, recover their original weight after immersion in water; nor is it necessary that the whole skin should be brought into contact with that liquid; the same result is obtained if merely the tail and hinder parts are im-

mersed. Gaseous substances also find entrance through the skin. If the hand be put into a bell-jar containing oxygen, nitrogen, or carbonic acid at the pneumatic trough, absorption of those gases ensues. Probably it is a standard function of the skin to permit a partial arterialization of the blood, atmospheric oxygen being exchanged for carbonic acid through it, an action the residual trace of the community of function between the skin and mucous membrane. In the case of some animals this cutaneous respiration is well marked.

Summary of the functions of the skin.

Recapitulating now the more important actions of the skin, the following statement may be made: It regulates, to a certain extent, the amount of water in the system, disposing of it, as the case may be, either as sensible or insensible transpiration. The water doubtless maintains its liquid condition until it presents itself at the mouths of the sudoriparous ducts, moistening the general surface of the skin, and then being evaporated; or, if the supply be greater than can be thus removed, it accumulates as drops of sweat. There appears to be no substantial reason for believing that any portion of water transudes directly through the structure of the cuticle, since the scales which compose it are of an impervious and almost horny nature, and their interspaces are fortified against any such leakage by the oily exudations of the sebaceous glands. With the water thus presenting on the surface are many compounds which are also constituents of the urinary secretion. Among these, urea may be particularly pointed out, thus indicating a similarity of instrumental action between this organ and the kidneys, and this is farther substantiated by both containing provisions for the elimination and escape of the hydrocarbons; but besides these direct functions there are other very important collateral agencies which the skin exerts, and particularly as a regulator of temperature. In this respect the action is, to a certain extent, meteorological. But this has been previously treated of so much in detail that it is unnecessary to resume the consideration of it now.

CHAPTER XIII.

OF DECAY AND NUTRITION.

Of Decay: Loss of Weight in Starvation.—Interstitial Death.—Effect of Allotropism.
Of Nutrition: Nutrition for Repair and Nutrition for Remodeling, illustrated in the cases of Fat and Bone respectively.
Of Fat: Its Peculiarities, modes of Occurrence, and Origin.—Inquiry whether Animals ever form Fat.—Artificial Production of it.—Animals both collect it and make it.—Accumulation of it expends Nitrogenized Tissue.—Conditions of the Fattening of Animals.—Summary of the Sources, Deposit, and manner of Removal of Fat.—Its partial Oxidations.—Summary of its Uses.—Nitrogenized Nutrition.
Of Bone: The Skeleton.—Structure and Chemical Composition of Bone.—Sources of its Constituents.—The Process of Ossification.—Experiments on the Growth of Bone.—Influence of Physical Agents on Development and Nutrition.

OF DECAY.

Retrograde metamorphosis.

THE animal mechanism, as a condition of its activity, is constantly giving rise to wasted products, its parts in succession passing through retrograde metamorphosis or decay. From the elaborate organization which they have maintained, they go by degrees through a descending course, which brings them nearer and nearer to the inorganic state. Thus the fats, falling from one step to another, finally emerge from the system as carbonic acid and water, and thus the complex atom of protein degenerates into those substances and ammonia.

Loss of weight in starvation.

To this steady wasting away we offer no resistance. Having no interior principle of conservation, the organism delivers itself up unresistingly, and, if its necessary supplies be withheld, very soon succumbs. The experiments of Chossat show that, taking the mean of forty-eight cases, including rabbits, Guinea-pigs, turtle-doves, pigeons, hens, and crows, the body loses 39.7 per cent. of its weight before death by starvation ensues; that mammals, during the process of inanition, lose daily 4.0 per cent. of their weight; and birds, as indeed might be expected from their higher rate of respiration, 4.4 per cent. It follows, therefore, that such animals, under these circumstances, lose one twenty-fourth part of their weight per diem by destruction of tissue, a result which corresponds with that of Schmidt's experiments, which lead to the inference that the daily amount of properly-selected food which an animal requires must amount at least to one twenty-third of its bodily weight.

That the functional activity of a part implies destruction is very well

illustrated by the gradual waste of the muscles under use; that nervous activity is also dependent on oxidation is indicated by the appearance of alkaline phosphates in the urine. Generally, the more active the function, the shorter the life of a part; but even the hair, the teeth, the cuticle, the activity of which is very low, are no exceptions, for they, too, have a limit of duration, and provisions for repair or renewal. Thus, as the surface of the cuticle abrades, it is restored by the development of new cells below, and their gradual drying up into scales; and as regards the teeth, the second set arise, as it may be said, from germs which have been left by the first, so that when the crown of the deciduous tooth dies, and its fang and vascular arrangement are absorbed, the new tooth is ready to take its place.

Necessity of repair.

Since it is not merely superficial parts, as the hair, the teeth, or the cuticle, but also the deep-seated or interior ones, that undergo these changes, the appropriate designation of interstitial death has been introduced. The removal of the effete material is accomplished by the aid of the blood, which occasions partial or perfect oxidation, with a corresponding liberation of heat, and then, dissolving the products that have arisen, carries them away. We have heretofore discussed the question how it is that this oxidizing action of the arterial blood is limited to the dying parts, and how those which are yet capable of taking a share in organization are protected. It appears to me that we are obliged to admit, in the mechanism of living beings, those peculiar conditions which both simple and compound bodies may assume, and which are known as allotropic states in chemistry. The indifference to oxidation which carbon, under the form of diamond, presents, contrasts strikingly with the extreme combustibility of lamp-black. The ready oxidibility of phosphorus, which causes the shining from which it has derived its name, is no longer recognized in that other phosphorus which has been acted on by the more refrangible rays of the sun. And these are qualities which elementary atoms carry with them when they go into union with other bodies, as is well displayed by the two distinct forms of phosphureted hydrogen gas, bodies having the same composition, but the one spontaneously combustible and the other not. Some reasons have also been offered for imputing to the nervous system a control over these allotropic changes, and under this point of view we must regard it as having, for one of its prime duties, the regulation of decay. These conclusions receive weight from the consideration that in plants, in the economy of which no interstitial deaths are taking place, no nervous system is found.

Interstitial death.

Decay dependent on allotropic condition.

OF NUTRITION.

Interstitial death and retrograde metamorphosis imply removal; but, besides the removals of wasted material, on account of its inability to be any longer subservient to the uses of the economy, there are also subordinate removals, which are connected with the necessary remodeling of parts. Thus, during the growth of the skeleton, bone earth is transferred from one point to another, the osseous cavities enlarged or altered, and the substance taken from them is carried to other points where it is needed. Under such circumstances, the disappearing part is not, in reality, giving rise to useless products. The substance thus taken from the position it occupied is as valuable as it ever was, and accordingly it is employed over again.

Nutrition for repair and nutrition for remodeling.

The restoration of material in the place of that which is being consumed for use, and even the preservation of excesses which may be of value at a future time, is very well illustrated by the deposit of fat in the adipose tissue. Transference from point to point of material which has undergone no deterioration may be studied in the history of the growth and development of bone. To these cases in succession I propose to direct attention.

First. Of the use, sources, and manner of deposit of the fat.

The use of fat in the animal economy doubtless depends on its heat-making power; for, though there are many different varieties of this substance, solid and liquid, they are all characterized by an analogy of composition, all containing a great excess of unoxidized hydrogen. It is, indeed, on this peculiarity that their employment in domestic economy depends. They are all highly combustible, and evolve so much heat as to be very available for the production of flame.

Physiological relations of fat.

For the better understanding of the functions discharged by fatty substances, we may perhaps profitably offer the following statement of their chemical relations.

When a fat or oil is acted upon by an alkali, in contact with water at its boiling-point, decomposition ensues, a fatty acid and glycerine being disengaged, and the acid, uniting with the alkali, gives origin to a soap. During this action no oxygen is absorbed, but, since the compounds arising present an increase of weight, it is evident that there has been an assimilation of water. In view of these facts, it is therefore inferred that the oils and fats are composed of a fatty acid united with the oxide of a radical, to which the designation of lipyl has been given, and which, when it is displaced, combining with water, gives origin to glycerine.

Chemical peculiarities of fat.

Glycerine, which is a substance of considerable physiological importance, is a pale yellow liquid, of a sweetish taste, and attracting moisture

from the air. If fermented in a large quantity of water with yeast, it is converted into metacetonic acid. It occurs in the yolk of the egg, and also in the fats of the brain. By gradual oxidation it can give rise to lactic acid.

The physical properties of the fats depend, for the most part, on the nature of their acids. The fats derived from animals are of various degrees of consistency; they are colorless or white, lighter than water, bad conductors of heat. They are insoluble in water, and burn, in the presence of air, into carbonic acid and water, with the evolution of much heat. By the action of certain nitrogenized ferments they may be separated into their acid and glycerine, and by the action of pancreatic juice, as explained previously, may be brought into the condition of an emulsion. The more important of the animal fats are stearine, margarine, and oleine.

Places of occurrence of fat.

They are inclosed in cells accumulated in various parts of the system, such as in the orbit of the eye, around the heart, and among the muscles of the face, under the cutis, and within the bones. In morbid states they sometimes abound in the kidneys, liver, and spleen. They are also discovered in some of the animal fluids: thus they communicate to the chyle its characteristic property, and therefore likewise occur in the blood. In their relative amount they vary at different periods of life, being in a larger proportion in childhood, and again after the middle period. Their quantity likewise changes with physical changes, diminishing, for instance, after continued muscular exertion, and also by long exposure to cold.

Quantity of fat in the blood.

Though the amount of fat in the blood varies with the nature of the food, it can not, however, be increased, in a state of health, beyond a certain point, owing to the inability of the absorbents to receive more than a definite quantity. The serum of arterial contains less fat than the serum of venous blood; the blood of women more than that of men.

Fig. 107.

Fat-cell.

Fig. 108.

Adipose and areolar tissue.

The manner of occurrence of fat in organized structures is twofold: often it occurs in the free state, but also is very commonly inclosed in the interior of cells, as shown in *Fig.* 107, which is a fat-cell, *a* being the adipose membrane, and *b* the nucleus.

Fig. 108, adipose and areolar tissue: *a*, *a*, fat-cells; *b*, *b*, fibres of areolar tissue.

Fats arise from carbonic acid and water, returning thereto.

Respecting the origin of the fat substances in plants there can be no question. They are derived from the decomposition of carbonic acid and water by those organisms under the in-

fluence of the rays of the sun. It is interesting to remark that to these same binary bodies do the fats return after accomplishing the successive stages of their metamorphosis in the economy of animals. From carbonic acid and water they come; to carbonic acid and water they return.

But the origin of the fatty substances of animals is by no means so clear. One of the questions which have been debated in chemical physiology is, Do animals collect from their food all the fat they require, or have they the power of making it for themselves? In the preceding chapter, under the description of the origin of the butter of milk, we have, in part, anticipated the facts which might here be presented. Referring, therefore, to what has there been said, it will be sufficient now to admit the general conclusion that fats and oils very abundantly occur in plants.

Do animals collect or fabricate fat.

But instances are not wanting which show that from other sources than the vegetable kingdom, and by processes very different to those executed by plants, fats may be made from substances in which they did not pre-exist. We select some of these which have been offered by chemists who have asserted the power of the animal system for such a formation of fat.

1st. When an animal body is buried under certain circumstances, it does not undergo putrefaction, but changes into a fatty or soapy substance, adipocire. Attention was first directed to this fact on the occasion of exhuming many bodies from the cemetery of Innocents in Paris. Those which lay a certain depth beneath the ground were found to have undergone the change in question; but that it does not altogether depend on the condition of the earth of the grave, as respects moisture or other such physical state, I have myself had the opportunity of verifying in the case of a subject which had been buried for nineteen years, and which was disinterred in a condition of perfect preservation, so far as exterior appearance went, but which had been wholly converted into adipocire. Yet, from the same burying-ground, many other bodies were disinterred, but none had undergone a like change.

Supposed instances of its formation.

2d. When nitric acid is made to act on fibrin apparently deprived of its fat, an oily substance is disengaged.

3d. During the action of nitric acid on starch, in the preparation of oxalic acid, a like effect takes place, oily matter being set free.

4th. As has been described in a preceding chapter, butyric acid may be prepared from sugar, through the influence of casein, in the presence of carbonate of lime.

Though the conversion of albumenoid bodies into fat has not thus far been distinctly accomplished in an artificial way, no doubt can exist that it is possible. Indeed, the experiments of Quain and Virchow respecting the origin of adipocire have

Production of fat from albumenoid bodies.

led them to regard it as, at all events to some extent, arising from the albuminous constituents of the muscles being decomposed into fatty acids and ammoniacal salts. Wagner, Donders, Burdach, and others, have furnished many interesting experiments on the apparent transmutation of various bodies, such as pieces of coagulated albumen, crystalline lenses, etc., in the abdominal cavities of birds. These extraneous objects after a time become enveloped in, and in some cases permeated by, fatty material. But that this does not arise from metamorphosis of the protein body introduced was well proved by the last observer, who employed pieces of wood and the pith of elder with the same result.

The carnivora find fat in their food.

Whatever, therefore, may be the conclusion arrived at on the cases here introduced—whether, during a special metamorphosis, muscular tissue can pass into adipocire; whether from fibrin or starch, by the action of nitric acid, fats may be made, or whether these substances pre-existed in the material from which they appear to arise, and are only disengaged or set free—there can be no question as regards one great group of animals, the carnivora, that they find in their food a sufficiency of these hydrocarbons to meet all their wants. It is as respects the other group, the herbivora, that this question of the artificial formation of fats from substances in which they did not pre-exist, and particularly from albumenoid bodies, becomes interesting. Do the herbivora find in their food all the fat they require, or are they obliged to fabricate a part?

Do the herbivora ever make it?

Formation of fat by bees.

The question whether there exists in the animal mechanism a capability of forming fat from material in which it did not pre-exist may be considered as finally settled in the affirmative, after much discussion, by the repetition of Gundelach's experiment by Dumas and Milne Edwards. This experiment consisted in the feeding of bees with honey nearly free from wax, and determining the quantity of fat in their bodies at the beginning and end of the experiment, and also the quantity of wax in the comb that they made. The following table gives the result:

	Gramme.
Fat found in the body of each bee at the beginning	0.0018
Wax each bee consumed with the honey, not exceeding	0.0003
Whole amount of fat derived from food	0.0022
Wax secreted by each bee	0.0064
Fat and wax in the body of each bee at end of experiment	0.0042

From which it appears that a very large quantity of fat and wax had been produced.

The system continually generates fat.

Admitting thus that the animal system possesses the power of forming fat, it is probable that, under all circumstances, it carries forward that function, though it may be at different rates on different occasions. Such a production of fat probably com-

mences in the intestinal tube, the material from which it originates being both nitrogenized and non-nitrogenized. Thus, when ducks have been fed on albumen containing but little fat, the digested material in the intestine yields a larger proportion of fat than when they have been fed on clay, or even on starch. If the glands of the intestine secreted fat from the blood, it would be detected after feeding the birds with clay, and hence we may conclude that the source of the increase observed is from the albumen.

But, in addition to the part they thus make, a large portion of the fat of animals is undoubtedly obtained from the food. This is obviously the case with carnivora, and the same may, indeed, be said of the herbivora. Very many of the oleaginous bodies have a close chemical relationship to one another, so that they may be regarded as affording a series, the terms or members of which arise from successive partial oxidations; and since the fats are soluble in one another, they freely mix together, and therefore many of them may be found co-existing in the adipose tissues, some of them less and some of them more advanced in their progress of oxidation. Whether they have been derived from the food or by indirect processes made in the system, it is equally true in both instances that their primary source was in the vegetable kingdom. In the former case they occurred in the plant-structure as hydrocarbons, in the latter as amylaceous or nitrogenized bodies. Under the influence of the sunlight the vegetable tissues obtain them by decomposing carbonic acid and water, and to those two substances they return after they have undergone destruction in the animal organs, thus presenting a significant instance of the alternate passage of atoms from the inorganic to the organic state, and back again.

Plants furnish fat or the materials from which it is made.

The primary source of all fat substances is therefore in plants, which obtain them from the decomposition of the inorganic constituents of the air. The excess of hydrogen which characterizes this group of bodies in most instances is undoubtedly derived from the decomposition of water, and this explains the fact, frequently noticed, that the development of such hydrocarbons in plants is often accompanied by the simultaneous appearance of acids, for the hydrogen being appropriated by the former class, the residual oxygen gives origin to acids or is set free.

The quantity of fatty matter formed in the ordinary articles of food used by domestic animals seems to be amply sufficient to meet all their wants. If a calculation be made of the amount of such materials consumed by cattle during the process of fattening, it will be ascertained that the quantity used not only contains sufficient to account for the increase of weight, but also furnishes an ample supply for the portion which is destroyed by respiration. The fats

Quantity of fat in plants sufficient for animals.

thus contained in plants are often absorbed with but little alteration. The fattening of cattle with linseed-cake gives rise to an accumulation in their adipose tissues of an oily material of unusual fluidity, and it is a matter of common observation, as previously mentioned, that when strong-smelling oils have been accidentally used, their flavor will be imparted to the secretion of the mammary gland.

The quantity of fat in articles of food is commonly estimated by the solvent action of sulphuric ether. It should, however, be understood that we can not with correctness regard all the matters extracted by that menstruum from plants as fat.

Thus, either by forming or by collecting from the food, a supply of fat is obtained, and this is absorbed by the lacteal system in the manner already described. But where fat is administered in excess, so that large quantities of it are retained in the system, a proportionate cell formation arises for the purpose of affording it a receptacle. The walls of such cells are composed of nitrogenized material, and herein is displayed the connection between the two groups of bodies, the albumenoid substance and the fats. There is reason to suppose that when, from the food, a sufficient quantity of nitrogenized material for this purpose can not be obtained, resort is actually had to the muscular fibre of the system itself, but when this also fails the fat accumulates in the blood.

The accumulation of fat requires nitrogenized tissue.

In the artificial fattening of animals, the indications to be complied with are very obvious: They are, 1st. To furnish an abundant supply of oleaginous material in the food; 2d. To prevent, as far as possible, waste by oxidation.

General conditions for the fattening of animals.

The first indication is satisfied by the purposed employment of oleaginous articles, as, for instance, linseed-cake, or by the selection, among ordinary food substances, of those which, like Indian corn, abound in oil. It is to be remarked that the increase of weight of an animal may take place in two ways: 1st. By adding fat to the deposit in the adipose tissues; or, 2d. By development of the muscles. It might perhaps be admissible to speak of the former as adipose fattening, the latter as albumenized. According as it has been subjected to one or other of these processes, an animal will be very differently prepared for undergoing severe exercise. A horse fed with Indian corn can not, under those circumstances, maintain himself as well as if he had been fed on oats. In the former case his adipose tissues have been developed, in the latter his muscular.

The second indication is met by resorting to every expedient which can restrain the action of the respired oxygen. A state of perfect quiescence is therefore to be observed. Muscular movement of every kind increases the activity of respiration. On the contrary, rest diminishes it.

If, in addition to this state of quiet or rest, sleep likewise be indulged in, the object is still more perfectly attained; and if a high temperature be resorted to, since this checks the oxidation needful for maintaining the system at its due temperature, this also diminishes the waste of the fat.

Under such circumstances, where every thing is done to give a supply of fat, and every thing to prevent its consumption, it may be caused to accumulate in the tissues to an extraordinary amount. But this very soon interferes with the action of the liver, one of the functions of which we have seen is the preparation of fat. And it may also be remarked that many of the diseases of that organ, especially those occurring in hot climates, meet their explanation on the principles we are here inculcating, the state of rest produced by lassitude, the warm and therefore expanded air that is breathed, and the improper resort to oleaginous articles of food.

The liver affected in that operation.

In view of the preceding facts, it may therefore be concluded that the interior source from which the adipose tissues are supplied is the fat contained in the plasma of the blood, into which it has been poured through the thoracic duct, or otherwise obtained from the digestion of food in the small intestine; and since the blood-cells contain a higher percentage of oily material than the plasma (2.2 per cent. may be extracted from them by ether, either as a phosphorized fat or glycero-phosphoric acid), they constitute reservoirs of supply to meet the exigencies of the system, there being a necessary relation between the quantity they can thus retain in store and the quantity contemporaneously existing in the plasma, a diminution of which at once establishes a drain upon the cells. Thus charged with these hydrocarbons, the plasma passes wherever there are adipose cell-germs, furnishing to them the special nutriment they require for their development into fat-cells, the wall and nucleus of which are derived from the blood, or, as we have mentioned, in certain cases actually from the muscular tissues. The amount of fat which can thus be held in reserve depends in part on the number of germs, in part on the supply of fat from the digestive organs, and in part on the supply of appropriate material for the walls and nuclei.

Summary of the sources, manner of deposit, and manner of removal of fat.

When the fat thus stored up is wanted, the cell wall in many cases deliquesces or wastes away, surrendering its contents back to the plasma, but probably much more frequently a transudation of the hydrocarbon takes place through it, analogous to what has been described as occurring in the blood-cells themselves. This demand upon the adipose tissues may originate for many reasons, since there may be a necessity for fat in the accomplishment of the various histogenetic operations going forward, or for those of retrograde metamorphosis, or for the maintenance of a normal state of the blood as respects its oleaginous ingredient, or for

the production of heat by immediate and final oxidation into carbonic acid and water.

Fats undergo partial oxidations in the system.

It is not to be supposed, however, that this final oxidation into carbonic acid and water always takes place at once or abruptly. Every thing shows that fats pass through successive gradations of retrograde metamorphosis, perhaps gradually losing by oxidation two atoms of carbon and hydrogen; and, indeed, there is reason to believe that, on special occasions, the opposite changes happen. Thus stearic acid may arise from margaric acid by deoxidation. It does not occur to any considerable extent in vegetable food, having thus far been only found in cacao butter.

Summary of the uses of fat.

In a summary of the uses of fatty substances may be mentioned the production of a high temperature by oxidation; their agency in metamorphosis, as displayed by the assistance they lend in gastric digestion; the function they seem to discharge in cell life, which would appear to be important if it be true that the nuclei of some cells are composed of fat; their relation in the formation of bile, and their probable connection with the production of hæmatin. Among their physical uses may be mentioned the equable manner in which they propagate pressures in all directions when they are in the liquid state, as is often the case; the manner in which they fill up vacuities, and communicate a roundness and solidity to the system; their low conducting power as respects heat, which enables them to economize the warmth of the body; their diminishing of friction among moving parts, as in the case of the muscles; and that they discharge some highly important function as respects the nervous system is proved by the manner in which they uniformly occur in tubular nervous tissue. In the general metamorphoses of the system they seem to take an important part. This may be inferred from the fact of their presence wherever cells or fibres are forming.

From what has been said respecting the connection of the fats with the metamorphoses of the system, it is obviously incorrect to regard them as constituting a purely respiratory element.

Nutrition of the nitrogenized tissues.

Conclusions similar to those which have been stated respecting the vegetable source of the fats might also be arrived at as regards the source of the nitrogenized constituents of the system. These likewise are found in plants; and thus, therefore, though the carnivorous animal may be said to be nourished by the carcass on which it feeds, it is nevertheless strictly true that its nutrient material is all from the vegetable world.

The repair of muscles, of nerves, of the skin, or other such highly organized parts, is dependent on the agency of cells. Since these are undistinguishable, or to all appearance perfectly alike, it becomes a matter

of curious inquiry how they should be able to occupy exactly the places and discharge with precision the functions of those which they are replacing? or, in the case of growth and development, why they should combine so as to take on a determinate, and, as it were, predestined form? How is it that such a variety of structures spring up from the same original cell? How is it that the two halves of the body have such a symmetrical conformation in a majority of instances, the one being the exact counterpart of the other, peculiarities which are often continued even after the supervening of morbid conditions, as shown in such cases as are known by the term of symmetrical diseases, in which a structural change affecting one side of the body affects also the corresponding part of the other side? It appears to me that these and other such instances of nutrition, growth, and development can only be explained by admitting, as a great and fundamental principle in physiology, that the primordial germ being in all instances alike, its mode of development will depend on the physical agents and conditions to which it is exposed: a principle which, though it may seem of little moment at the first view, carries with it consequences of the utmost importance at last.

Second. Of the structure and development of bone.

The skeleton in man is composed of 246 bones, which are usually divided into three groups, the long, flat, and irregular. Their uses are purely mechanical, such as to give support to the soft parts; to serve as levers on which the muscles, by their contractions, may act.

The skeleton.

In structure bone offers an imperfect division into the compact and spongy. The compact is, however, a porous mass full of cells and passages. Through it there pass, more particularly in the longitudinal direction, canals for containing blood-vessels and nerves: they are called haversian canals. These, which are well seen in a thin transverse section of bone as irregular circular openings, are surrounded with lamellæ, and in the basis substance occur hollow spaces, the lacunæ, which, presenting a dark aspect, were formerly mistaken for solid corpuscles; they are, however, cavities from which proceed minute channels or canaliculi. In form the lacunæ are irregularly oval; the canaliculi of those nearest to the haversian canal communicate directly with its cavity, and there is so complete an inosculation between adjacent lacunæ, by means of these delicate tubes, that the whole so-called compact structure of the bone may be said to present a connected system of lacunæ and canaliculi.

Structure of bone.

The diameter of these delicate channels of intercommunication is much too small to permit the passage of blood-cells, yet through them the plasma readily finds its way and thus carries forward the nutrition of the entire bone.

Fig. 109 is a photograph of a transverse section of part of human femur, showing the haversian canals surrounded by their concentric lamellæ, lacunæ, and canaliculi. The complete perviousness of the structure is demonstrated.

Fig. 109.

Transverse section of bone, magnified 50 diameters.

Fig. 110.

Lacunæ and canaliculi from frontal bone.

Fig. 110, lacunæ and canaliculi of human frontal bone.

Chemical composition of bone.

In chemical constitution, bone may be considered to be composed of two portions, organic and mineral: the former is gluten, and in the latter phosphate of lime greatly predominates, as the following analysis by Berzelius shows:

Analysis of Bone. (*Berzelius.*)

Cartilage (or gluten)	32.17
Blood-vessels	1.13
Phosphate of lime	51.04
Carbonate of lime	11.30
Fluoride of calcium	2.00
Phosphate of magnesia	1.16
Soda, chloride of sodium	1.20
	100.00

Separation of its organic and earthy bases.

An instructive separation of bone into its leading constituents may be accomplished by the action of hydrochloric acid or by calcination respectively. When a bone is soaked in dilute hydrochloric acid for a due length of time, its mineral constituent is removed, and the organic gluten is left in the shape of the original bone; or, if the bone be calcined in the open fire with free access of air, the organic material is consumed and the mineral material remains. A more critical examination shows that these constituents are not merely associated together—they are, in reality, chemically combined.

The different degrees of softness and hardness which bones from different animals present depend very considerably on the amount of water they contain. The gluten is doubtless, in all instances, derived from

the metamorphosis of albumenoid bodies, a conclusion which is well illustrated by what we observe in the case of the incubating egg. In the adult the source of the bone-earth is twofold: in part it is derived from the food, and in part obtained from the remodeling and changes of the bones themselves. In speaking of the composition of milk, we have already described how, through the casein of that secretion, a supply of phosphate of lime is secured for infant life.

Origin of the organic and earthy matter.

At its first formation, bone consists of a gelatinous material, which gradually becomes condensed and cellular, presenting what is termed the cartilaginous state. In this material vascular canals arise, which, concentrating toward one spot, give origin to the point or centre of ossification. Simultaneously, the structure of the cartilage becomes modified, its nucleated cells are elongated, nucleoli arising, and smaller cells forming. These reach maturity, and are separated from one another by the material derived from the deliquescence of their parent cells, which has simultaneously been taking place. The progress of these changes may be studied by examining the calcifying cartilage nearer and nearer to the point of ossification, to which, as we approach, we find that the cells become more and more numerous, a general arrangement into a columnar form being now apparent.

The process of ossification.

The deposit of mineral material commences at the point of ossification, and proceeds between the columnar arrangement of cells, lateral branches between the individual cells being successively given off, a bony network thus arising which is pervious in every part. In the human embryo the cartilaginous stage is completed in the sixth week, and ossification commences first in the clavicle during the seventh.

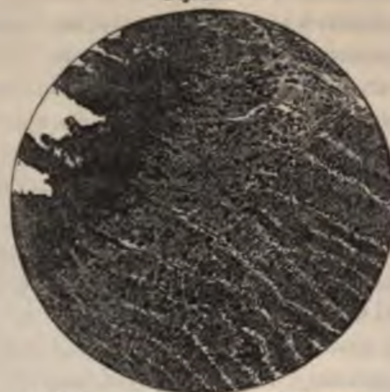
Fig. 111.

Ossifying cartilage, magnified 10 diameters.

Fig. 111, perpendicular section of the ossifying border of the shaft of the femur of a child a fortnight old: *a*, cartilage in which the cells, the nearer they are to the ossifying border, are in more extended longitudinal rows; *b*, ossifying border: the dark streaks indicate the progressive ossification of the intercellular substance, the clear ones the cartilage cells, which ossify subsequently; *c*, compact layer of bone near the ossifying border; *d*, the substantia spongiosa formed in the osseous substance by absorption, with cancelli, *e*, *e*, the contents of which are not shown. (Kolliker.)

Fig. 112, photograph of ossifying cartilage, the dark portions showing the region of complete ossification. The columnar arrangement of the cartilage cells is very apparent.

Fig. 112.



Ossifying cartilage, magnified 50 diameters.

Fig. 113.

Ossifying femur.

Fig. 113, femur of a child a fortnight old, natural size: *a*, substantia compacta of the shaft; *b*, medullary cavity; *c*, substantia spongiosa of the shaft; *d*, cartilaginous epiphysis, with vascular canals; *e*, osseous nucleus in the inferior epiphysis. (Kolliker.)

Growth of bone shown by silver rings and madder.

When silver rings are placed upon the shaft of a growing bone at a measured distance, subsequent examination shows that that distance still remains the same, though the bone may have become much longer. If such a ring be permitted to remain a sufficient period of time, it will eventually be found in the interior of the bone. When madder is mixed with the food of pigs, its coloring matter so unites with the phosphate of lime of their bones as to impart to them a red tint. If the animal submitted to the experiment be very young, the whole skeleton may be tinged in a single day, a more close examination showing, however, as might be expected, that the portion most completely acted upon is that nearest to the vascular surface. In older animals the coloring goes on more slowly; the portion which shows the effect most strikingly is between the shaft and extremities, more particularly upon the surface. If the madder be given periodically and then withheld, alternate layers of a red and white appearance are produced.

Conclusions drawn from such experiments.

From these experiments, it may be inferred that the growth of a bone is not uniform in all parts. Young bones grow chiefly toward the extremities; nor is the growth cumulative, the parts already deposited being ever after preserved; for, if that were the case, it would not be possible for a ring placed in such a manner as has been described to find its way into the medullary canal. For that to

occur, there must have been an absorption or removal of the pre-existing parts. The tinging by madder shows that growth is taking place wherever the plasma of the blood can have access, and this not alone upon the proper vascular surfaces, but also interstitially.

It thus appears that bone, solid and dense as it is, is the seat of continual changes, which, though they may go on with more activity in the growing state, take place also when the structure has reached maturity or apparent perfection. From one portion a part is removed, on another additions are made, the method by which this is accomplished being through the access of the blood-plasma, which finds its way to every part by reason of the pervious structure of the mass.

Sources from which material is derived.

As to the sources from which the phosphate of lime is derived, though doubtless the food offers it in considerable quantity, there are many reasons for inferring that the identical portion which has been removed from one part is used for the extension of another; and thus we may say that there is a plastic operation continually going forward, a remodeling, so as to adapt the structure to its new conditions if in a growing animal, or to maintain it in good repair if in an adult.

Turning from the two cases with which we have been thus occupied, the development and maintenance of the adipose and osseous tissues, to the phenomena of nutrition generally, we may conclude that there are several sources from which material for these purposes may be derived: a part may be obtained by absorption directly from the food; a part may be manufactured or fabricated in the system itself, or may be taken from some locality therein in which it has become redundant or useless, and transferred elsewhere to the point at which it is required.

The medium through which these additions and exchanges for the purpose of development or remodeling are accomplished is of course the blood. It bears with it, wherever it circulates, the substances that are demanded—fibrin for muscles, bone-earth for the skeleton, fat for the adipose tissues.

Parts are developed and modeled by the influence of physical agents.

It remains for us to inquire into the laws of deposit and development involved in these processes, that is to say, why, for example, is phosphate of lime laid down at the points where the phosphate of lime has been, or, if growth be taking place, why are the accretions arranged in a definite way both as respects size and shape? Upon this inquiry I do not propose at present to enter, since it is closely connected with the general doctrine of development, which will have to be considered in detail in the next book. We shall then find that reasons may be assigned for the deposit of given substances in places that have been vacated by others of the same kind, as in the nutrition of muscles. We shall also then have to consider the

laws of development from a much more extensive point of view, introducing the doctrine of the paramount influence of physical causes in this respect, and perhaps we shall find ourselves brought to the conclusion that the progressive career of a cell is absolutely dependent on the physical conditions to which it is exposed, and that there is nothing extraordinary in the circumstance that two cells placed under conditions which are alike will develop alike; that, therefore, a part which is being repaired will have its additions made in the same places, of the same material, to the same extent, and of the same form as the part which has been removed.

CHAPTER XIV.

OF THE NERVOUS SYSTEM.

Divisions of the Nervous System.—Cerebro-spinal and Sympathetic.—Fibrous and Vesicular. Structure and Functions of Nerve Fibres.—Centripetal and Centrifugal.—Rate of Conductibility. Anatomical Examination of the Structure and Functions of Nerve Vesicles.—They diffuse Influences, are Magazines of Force.—Element of Time introduced by Registering Ganglia.—Oxidation necessary to Nerve Activity.—Necessity of Repair and Rest.—Electrical Examination of the Functions of Vesicles.—Anatomical and Electrical Examinations agree.

Automatic Nerve Arc.—Cellated Nerve Arc.—Multiple Arcs.—Commissures.—Registering Nerve Arcs.—Sensorium.—Influential Arc.

Suggestions derived from cerebral Structure respecting the Soul.—Its independent Existence and Immortality.

Ideas of Time and Space.—Objective, subjective, and impersonal Operations.—Vestiges of Impressions and their Interpretation.—Finite Nature of Knowledge.—Mental Emotions.

Importance of the nervous system.

THE parts and functions which have been thus far described stand in subordination to the important system on the study of which we now enter. It may be truly said that the position of any animal in the scale of life is directly dependent on the degree of development of its nervous system. Through this it is brought in relation with the external world, deriving sensations or impressions therefrom; through this, also, all voluntary muscular contraction takes place. Whatever the grade of intelligence may be, the degree of development or expansion of the nervous system is in close correspondence thereto, from the lowest conditions in which it is first making its appearance in tribes which are scarcely distinguishable from vegetable forms, up to its highest elaboration in the cerebro-spinal system of man.

Imperfect condition of the subject.

The physiologist has to confess that in this, which is, without doubt, the most important part of his science, the amount of what is known with exactness is limited: indeed, so great an obscurity rests upon the functions of the nervous system that he has to content himself rather with the description of structure than offer

the explanation of action. Yet even now a few leading facts have been determined, which foreshadow the attitude in which the whole subject will stand when it comes to be better understood. Among these may be numbered the localization of special functions in special parts of the nervous centres, as was observed by Gall; the double office of the spinal nerves, first recognized by Bell, that their anterior roots are motor and posterior sensory; the conversion of impressions made at the periphery into motions, reflex action, as it has been termed, first clearly recognized by Hall; the relation of the ganglia at the base of the brain to the cerebrum and the spinal cord, as shown by Carpenter; and particularly the general condition on which the activity of the entire system depends, that it undergoes oxidation or waste, and, among other products, gives origin to salts of phosphoric acid.

Division of the nervous system into cerebro-spinal and sympathetic.

For the sake of convenience of description, the nervous system is usually regarded as consisting of two portions, the cerebro-spinal and sympathetic. The former is composed of the spinal cord, the brain, the nerves proceeding from them, and their ganglia; the sympathetic is composed of a series of ganglia, united by intercommunicating threads on each side of the vertebral column, and supplying branches to the coats of the blood-vessels and viscera of the great cavities. Both portions contain two kinds of structure, a fibrous and a vesicular. The latter is found in various situations; the former serves to connect those masses with one another, or to furnish means of communication from point to point; the office of the ganglia, or nervous centres, is for the reception of impressions and the origination of motions. In the brain the impressions of external circumstances are, as it were, registered, and from it originate the processes of intellection.

Fibrous and vesicular structure.

Connection of metaphysical philosophy.

The study of this portion of the mechanism of man brings us therefore in contact with metaphysical science, and some of its fundamental dogmas we have to consider. Nearly all philosophers who have cultivated, in recent times, that branch of knowledge, have viewed with apprehension the rapid advances of physiology, foreseeing that it would attempt the final solution of problems which have exercised the ingenuity of the last twenty centuries. In this they are not mistaken. Certainly it is desirable that some new method should be introduced, which may give point and precision to whatever metaphysical truths exist, and enable us to distinguish, separate, and dismiss what are only vain and empty speculations.

So far from philosophy being a forbidden domain to the physiologist, it may be asserted that the time has now come when no one is entitled to express an opinion in philosophy, except he has first studied physiology. It has hitherto been to the detriment of truth that these processes

of positive investigation have been repudiated. If from the construction of the human brain we may demonstrate the existence of a soul, is not that a gain? for there are many who are open to arguments of this class, on whom speculative reasoning or a mere dictum fall without any weight. Why should we cast aside the solid facts presented to us by material objects? In his communications throughout the universe with us, God ever materializes. He equally speaks to us through the thousands of graceful organic forms which are scattered in profusion over the surface of the earth, and through the motions and appearances presented by the celestial orbs. Our noblest and clearest conceptions of his attributes have been obtained from these material things. I am persuaded that the only possible route to truth in mental philosophy is through a study of the nervous mechanism. The experience of 2500 years, and the writings of the great metaphysical intellects, attest with a melancholy emphasis the vanity of all other means.

Whatever may be said by speculative philosophers to the contrary, the advancement of metaphysics is through the study of physiology. What sort of a science would optics have been among men who had purposely put out their own eyes? What would have been the progress of astronomy among those who disdained to look at the heavens? Yet that is the preposterous course which has been followed by the so-called philosophers. They have given us imposing doctrines of the nature and attributes of the mind, in absolute ignorance of its material substratum. Of the great authors who have thus succeeded one another in ephemeral celebrity, how many made themselves acquainted with the structure of the human brain? Doubtless some had been so unfortunate as never to see one! yet that wonderful organ was the basis of all their speculations. In voluntarily isolating themselves from every solid fact which might serve to be a landmark to them, they may be truly said to have sailed upon a shoreless sea from which the fog never lifts. The only fact which they teach us with certainty is that they know nothing with certainty. It is the inherent difficulty of their method that it must lead to unsubstantial results. What is not founded on a material substratum is necessarily a castle in the air.

Returning now to the general description of the nervous mechanism, and following the division above indicated, we shall consider, first, the fibrous element of the nervous system, and, second, the vesicular.

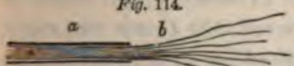
Fibrous or tubular portion.

First. Of the fibrous there are two varieties, one belonging to the cerebro-spinal, and the other to the sympathetic. The former may be described as a delicate membranous tube containing a semi-fluid material, and presenting under the microscope a pellucid glassy appearance when examined in the recent state; a spontaneous separation or partition, however, soon ensues, a white material or medul-

la appearing immediately within the membranous tube, and affording a contrast to the portions which are toward the centre or axis. In this state the nerve-tube presents the appearance of parallel lines toward its periphery, the outer one corresponding to the membranous sheath, and the inner to the internal limit of the coagulated material. In this condition the tube is very prone to assume a beaded appearance, either by the influence of pressure, or even spontaneously. Names have been given to distinguish these parts from each other; the central grayish portion is called the axis cylinder or axis band, since it may be of a flattened shape; and the material which surrounds it, intervening between it and the membranous investment, is designated the medulla or white substance of Schwann. There can be no doubt that the membranous tube, the white substance, and the axis cylinder discharge different physiological functions. In chemical composition they also differ: the tube is a nitrogenized structure, the white substance oleaginous, and the axis cylinder is supposed to be nitrogenized also. In the first development, the axis cylinder is first formed, and the white substance then cast round it.

Membrane, white substance of Schwann, axis cylinder.

Fig. 114.



Axis cylinder of nerves.

If a portion of a nerve, *a*, *Fig.* 114, be placed in concentrated acetic acid, the axis cylinders of its included tubes will, in the course of a day or two, be seen protruding in a brush-like form, as at *b*, the effect being very well shown when the nerve is sufficiently slender to be subsequently examined by the microscope.

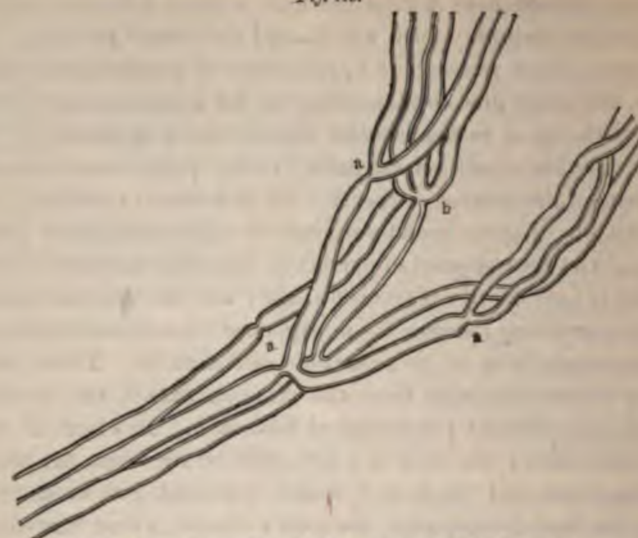
The nerve fibres run in a direct course to their point of distribution. Of their manner of termination we shall speak subsequently; here, however, it may be remarked, that occasionally they exhibit preparatory terminal branchings, as shown in *Fig.* 115, p. 262, observed by Kolliker in the case of the frog: *a*, *a* being bifurcations, *b* a trifurcation of a small twig from the cutaneous thoracic muscle. Similar subdivisions of the ultimate ramifications have been noticed in the amphioxus, fishes, insects, and it is certain that they also occur in man.

Terminal branchings of nerve fibres.

The sheath of the nerve fibres is an elastic membrane, which is neither acted on by dilute alkalies nor by boiling, but is soluble in concentrated acetic acid and strong solutions of potash and soda. By nitric acid it is stained yellow, and, though not identical with elastic tissue, has a certain resemblance thereto, approaching, however, more nearly to a protein substance. The axis cylinder is, as is shown by its behavior with reagents, a protein substance, differing, however, from syntonin and also from blood fibrin. From the latter substance it is distinguished both by the difficulty with which it dissolves in acetic acid and in a solution of nitre, from the former by its insolubility in hydrochloric acid.

Chemical reactions of the parts of nerve fibres.

Fig. 115.



Subdivision of nerve fibres in the frog, magnified 350 diameters.

Of such fibres, arranged parallel to each other in bundles, the bundles united by fibro-cellular tissue, nerves are composed, the tissue not only accomplishing that mechanical object, but also affording a nidus for blood-vessels, which run in a course parallel to the nerve fibres. Though we have spoken of those fibres as cylinders, they, in reality, approach more nearly to the figure of acute cones, since, though their diameter is from the $\frac{1}{2000}$ to the $\frac{1}{3000}$ of an inch in the nerve trunks, they diminish to the $\frac{1}{10000}$ or the $\frac{1}{14000}$ of an inch as they reach the nerve centres, and, in the same manner, their diameter becomes less as they branch off in their peripheral distribution. In the brain, as they pass through the medulla to the cortical part, they exhibit a similar diminution.

Form and size of nerve fibres.

The sympathetic fibres differ from the preceding in appearance. Being of a yellowish-gray color, and only about half as large, they do not show the separation into an axis cylinder and white investment after death, as is the case with cerebro-spinal fibres; they may therefore be regarded as being more homogeneous in their construction, or possessing a constitution like that of the other kind of fibres when they undergo diminution and approach their central or peripheral termination. Even in the cerebro-spinal fibres the quantity of white substance present is very variable; the retina, the olfactory organ, and the Pacinian corpuscles furnish instances of its absence. The sympathetic, gray, or gelatinous fibres, as they are indifferently called, contain many nucleated corpuscles, which may be rendered very distinct by the action of acetic acid.

Character of sympathetic fibres.

Nerve fibres terminate in various ways. Their ends may thin out and become free, or they may form a loop, and so return back in their course. Each nerve runs in an unbroken line from its origin to its termination, but between the adjacent ones intercommunication is established by the formation of plexuses. On the other hand, as the fibres are preparing to enter the nervous centres, the membranous tube dilates so as to receive a nerve vesicle, with which the diaphanous axis cylinder is thus brought in contact. Where corpuscles are received into the membranous sheath, it is not always certain but that the fibre has some other termination beyond. Some have supposed that sensitive fibres differ from the motor ones in the circumstance that the former alone are brought in connection with the corpuscles, but this is very unlikely.

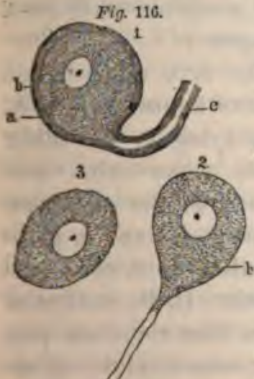
Manner of termination of nerve fibres.

Manner of reception of vesicles.

Second. The vesicular nervous substance is composed of nucleated cells containing a granular substance, with which there are intermixed, especially near the nuclei, pigment granules. These granules, however, are sometimes absent, as in the vertebrata. The nucleus of each ganglionic vesicle often presents a nucleolus; the diameter of the vesicle varies from $\frac{1}{300}$ to $\frac{1}{1250}$ of an inch. These vesicles are found in the nerve centres, their coloring material communicating to those parts the peculiar tint they display. In shape they vary very much, some being spherical, some ovoid, and others caudate, exhibiting processes which are filled with granules, or which, becoming eventually transparent, communicate with similar processes from other cells, or are continuous with the axis cylinders of the nerve-tubes. According to Axmann, the axis cylinder is a continuation of the nucleus of the cell. The ganglion vesicles, as they are termed, are characterized by containing a large amount of phosphorized oil, and it is probable that the oxidation of this material is a condition of their functional activity.

The vesicular portion.

Fig. 116.



Nerve-cells, magnified 350 diameters.

Fig. 116, ganglion globules (nerve-cells), from the Gasserian ganglion of the cat. 1. Cell, with short pale process, showing the origin of a fibre; *a*, sheath of the cell and nerve-tube, containing nuclei; *b*, cell membrane of the nerve-cell. 2. Cell, with the origin of a fibre without sheath; *b*, cell membrane of the nerve-cell. 3. Nerve-cell, deprived, in the preparation of it, of its membrane and external sheath. (Kolliker.)

Fig. 117, p. 264, bipolar nerve-cell of the pike, continued at each end into nerve-tubes. *a*, sheath of the nerve-cell; *b*, sheath of the nerve; *c*, medulla; *d*, axis cylinder continuous with the

Fig. 117.

Bipolar nerve-cell, magnified 350 diameters.

contents of the nerve-cell, *e*, which have shrunk away from the sheath after action by arsenious acid. (Kolliker.)

Fig. 118, caudate nerve vesicle of the multiple kind: *a*, the nucleated vesicle; *b*, its processes.

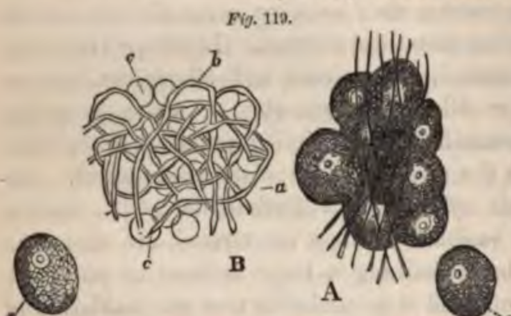
Fig. 118.

Multipolar nerve-cells, magnified 200 diameters.

These probably are continuous with the axis cylinders of the nerves, in connection with the vesicle.

Fig. 119, tubules and nerve-cells: A, from sympathetic ganglion; *, a separate cell, showing its pellucid nucleus and nucleolus: B, from the gray substance of human cerebellum: *a*, *b*, plexus of primitive fibres; *c*, nucleated globules; *, a separate cell from human ganglion of Gasser. (Wagner.)

Fig. 119.



Nerve cells and tubes, magnified 350 diameters.

Fig. 120, tubules and nerve-cells of human brain: A, nerve-cells lying in the midst of varicose nerve-tubes and blood-vessels in the substance of the optic thalamus: *a*, globule more enlarged; *b*, small vascular trunk: B, B, multipolar nerve-cells from the dark portion of the crus cerebri. (Purkinje.)

Fig. 120.

Human nerve tubules and cells.

Such being the construction of the fibrous and vesicular material, we may next inquire into their functions.

FUNCTIONS OF NERVE FIBRES.

Functions of nerve fibres. That the function of nerve-tubes is to conduct impressions, is proved by many different facts. On putting a ligature round a nerve, or cutting it across, it no longer transmits the usual influences. A more critical examination shows that impressions made on the external extremities of a nerve are conveyed by it to the centres, and the influences originating in the nervous centres are conducted along such trunks to the parts to which they are distributed. This double duty therefore implies that there are two classes of tubes, the centripetal and centrifugal, though thus far no structural difference between them has been detected. They can not of themselves either originate impressions or motions, these in every instance arising from external or central agency. **Centripetal and centrifugal fibres.** The centrifugal fibres, when cut across, may show no effect if the part still remaining attached to the nerve centre is irritated; but if the other part connected with the periphery be pressed upon or pinched, muscular contraction, that is, motion, results. If centripetal fibres be examined in like manner, the part connected with the periphery being irritated, no result arises; but if the part connected with the centre be irritated, sensations, general or special, as the case may be, are perceived. These several effects ensue when the motor or sensory nerve is intact; for, on irritating the one or the other, motion or sensation, as the case may be, is produced. If the whole trunk of a centripetal nerve be irritated, the mind refers the sensation to all those parts to which the branches of that nerve are distributed; if a part only, then the sensation is limited to those portions to which the fibrils of that part go; but, besides this, the mind also recognizes the particular spot upon the trunk to which the irritation has been applied. In like manner, when the entire trunk of a centrifugal nerve is irritated, all the muscles which it supplies contract; or, if only a part, then those muscles which are supplied from that part. From the anatomical fact that a nerve-tube does not anastomose with its neighbors, the influences which it conveys are transmitted along it without any lateral diffusion, and every fibre discharges one duty, and one alone. **Unity of function in the nerve fibres.** The centripetral can never assume the function of the centrifugal; and in the case of nerves of special sense, there is the same restriction: the optic nerve can not transmit the impressions of sounds, nor the auditory the vibrations of light; the nerves of common sensation are affected neither by one or the other, but they are by variations of temperature. **Rate of conductibility in nerves.** The velocity with which these influences pass along nerve fibres is indefinitely less than that with which electricity moves in a metal conductor. Thus far, however, no satisfactory measure of it has been obtained.

The experiments of Helmholtz give, for the rate of propagation, from 83 to 88 feet per second in the frog, and in man 200 feet, the velocity rising with the mean animal heat. At one time it was thought that there are perceptible differences in this rate in the same nerve of different individuals, or in different nerves in the same individual, but these conclusions are admitted to be erroneous, or to be explained upon another principle. It can not be denied that there is a general resemblance between the manner in which a nervous fibril transmits its influences and that in which a conducting medium conveys an electric current, though the velocity may be very different. There is a resemblance between the arrangement of the axis cylinder surrounded by its white substance and membranous tube, and that of a metalline wire wrapped round with silk, or other non-conducting material in many electrical arrangements. An electric current artificially transmitted along a nerve trunk will, as the nature of that trunk may be, give rise to muscular contraction, or produce general or special sensations, or originate reflex action. For these reasons, it has long been supposed, by many physiologists, that the influence which passes along nervous fibres is analogous to electricity, if it be not identical therewith; but all attempts to prove the existence of an electric current, either in the centripetal or centrifugal fibres, have thus far been abortive. It may, however, be remarked, that the arguments which are commonly presented against the hypothesis of the identity of the nervous agent and electricity are but of little weight when critically examined. Thus it is said that an electric current, passing along a nerve fibre, spreads laterally, whereas the nervous agent never does; but this is all dependent upon that quality formerly known among electricians as intensity. There is no reason to suppose that a thermo-electric current, the intensity of which is very low, would exhibit such a lateral propagation; whereas a voltaic current, whose intensity is high, does it without difficulty. Moreover, though it has been stated that the electric conductibility of a nervous trunk is indefinitely worse than that of a metal, even lower than that of a bundle of muscular fibre, it should be remembered in these discussions that the conducting power is in the axis cylinder, and no attempt has ever yet been made by any experimenter to isolate that structure and submit it to proper examination. It is just the same as though we should take a bundle of copper wires, each one of which is separated from its neighbors by a layer of non-conducting fat; that we should cut out a section of such a construction with a pair of scissors, and then attempt to determine its conductibility. That, under any circumstances, would be low enough; and the chances are that the non-conducting material would be smeared over the ends in the act of making the section, and the specimen refuse to conduct at all. In a similar manner, we may dispose of

Resemblance between the nerves and electrical conductors.

all those experiments which have been brought to prove the dissimilarity of electricity and the nervous agent, by intervening a piece of metal between a section of a nervous trunk, it having been found that under such circumstances the nervous influence does not pass.

Nervous activity depends on arterial blood.

The physical condition upon which the activity of the nervous mechanism depends is the supply of arterial blood; for, although the nerve fibres never receive or are penetrated by blood capillaries, these latter run in company with them in the nervous fasciculi. It would appear, however, that the supply of arterial blood is of far less moment in the function of the nerve fibres than it is in that of the nerve centres. This is shown by the limited supply given to the former, and the abundant one to the latter; by the comparative effect of a stoppage of the blood circulation, in which case the action of the nerve centres is instantly arrested, whereas that of the fibres may continue for a long time. On the whole, there are strong reasons for believing that the conductibility of the nerve fibres is as purely physical as is that of a metal wire, and that the supply of blood that they receive is only for the purpose of maintaining their construction in a perfect state.

Identification of the class of a nerve.

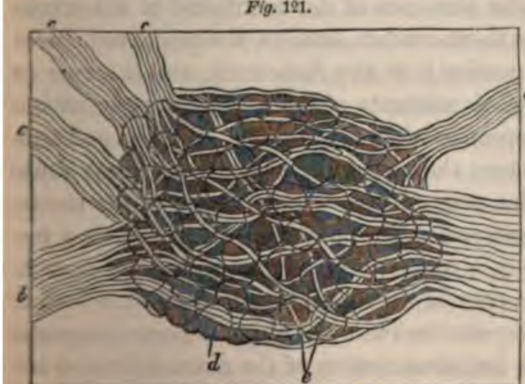
We have stated that there are nerves the functions of which are essentially different, such as the centripetal or sensory, and the centrifugal or motor. The identification of the class to which a nerve under examination belongs, may sometimes be made by examining its manner of distribution, or its ganglionic connection; sometimes by experiment, by making a section and irritating the cut extremities. In these cases, however, caution has to be exercised in coming to a conclusion.

FUNCTIONS OF NERVE-CELLS.

Function of nerve vesicles.

The nervous fibres having for their duty the conduction of external impressions and the transmission of nervous influences, the nerve-cells or vesicles are for the reception of those impressions and the origination of those influences. The nerve centres or ganglia are made up of vesicles, granules, and nerve-tubes conjointly.

Fig. 121.



Dorsal ganglion of mouse.

Fig. 121, dorsal ganglion of the sympathetic nerve of a mouse. *a*, *b*, cords of connection with

adjacent ganglia; *c*, *c*, *c*, *c*, branches to the viscera and spinal nerves; *d*, nerve-cells; *e*, nerve-tubes traversing the ganglion. (Valentin.)

Function of nerve-cells considered anatomically.

For the explanation of the function of the nerve centres, it is essentially necessary that we should have clear views of the function of the nerve vesicles. It has appeared to me that their duty is manifested by their anatomical relations. The influence, whatever it may be, which passes along a nervous cord, is completely isolated therein, and never leaves the fibril in which it is passing from its origin to its termination. It is isolated by the white substance of Schwann. But it is very plain, as a thousand phenomena of the nervous system prove, that there are places of escape for this influence, although it may be confined in the nerve-tube, and these places can be no other than the vesicles. Their caudate aspect, or multipolar form, as it is often termed, will bear no other interpretation. The disturbing influence, coming along the axis cylinder of a nerve-tube, finds itself delivered into the granular material in the interior of a vesicle, a material physically continuous, in the opinion of many physiologists, with the structure of the axis cylinder. Through this granular material the influence is transmitted, and if the vesicle should have on its distant contour two or more nerve-tubes connected with it, it would seem to be the necessary result of such a state of things that the influence will pass down all those channels. For these reasons I regard the nerve vesicles as being constructions for the purpose of opening out the closed nerve tubules, and permitting them to deliver their energy into new tracts.

They permit the influence to escape into new channels.

Diffusion of influence in this granular material.

But more than this. Whatever may be the manner in which the nervous influence is propagated, or conducted from point to point of the granular material within the vesicle, there must be now, since there is no structure to prevent it, a lateral spreading of effect. It is not to be supposed that the passage is made in a direct line, from the terminus of the centripetal to the origin of the centrifugal fibre, across these caudate vesicles, and restricted thereto. There is no isolator to confine it in any such track, and it seems to follow of necessity that the whole contents of the vesicle must be affected, and this irrespective of its magnitude. Such a condition of things introduces the suspicion of a second great duty which the vesicles may discharge in retaining within themselves, at all events for a short period, the influences that have thus escaped laterally, and thus they become temporary magazines of power. And perhaps this may be the true interpretation of the action of unipolar and bipolar vesicles; the unipolar being a capsule for the collection and conservation of the entire delivered influence, the bipolar to admit of the passage onward of a large portion of

Vesicles retain impressions, and are magazines of force.

Unipolar, bipolar, multipolar vesicles.

the force, but by lateral diffusion to preserve or delay a part, and the multipolar at once permitting of conservation and of a discharge into, perhaps, a multitude of new channels.

Interference of impressions.

Upon the same principle that multicaudate vesicles permit of the escape of nervous influence from the single channel in which it has been coming into many new ways, so likewise they must be the seats of the interference of influences delivered into them from many centripetal fibres at the same time. Thus we may imagine a tricaudate vesicle into the granular material of which an influence is delivered simultaneously by two centripetal fibrils, and these, reacting on one another in the interior of the vesicle, give rise to a resultant which may differ from them both, and this is passed on through the third, the centrifugal fibril.

Regarded in this way, the function of a nerve vesicle may therefore be stated to be, 1st. To permit the escape of an entering influence out of the solitary channel in which it has been isolated into any number of diverging tracts; 2d. To combine influences which are entering it from various directions into a common or new result; 3d. By permitting of lateral diffusion to take off and keep in store for a certain duration a part of the passing influence.

Retention of the vestiges of impressions.

Our attention can not fail to be arrested by this last effect; for if there be a property which is characteristic of the nervous mechanism in its utmost degree of development, it is this of retaining the relics or traces of impressions which have formerly been made upon it. As it goes on increasing in perplexity as we rise through the animal series, the provision for the retention of such impressions becomes more and more strikingly marked. Ganglionic masses, which, from their position and structure, are marked out for this duty, appear in that ascending scale in increasing magnitude. To these we may aptly apply the designation of registering ganglia, since they truly store up the traces of ancient impressions and keep them in reserve. These ganglia must, moreover, be the scenes of the interaction and interference of the impressions they thus contain.

Registering ganglia.

Introduction of the element of time.

The registering ganglia thus introduce the element of time into the action of the nervous mechanism. The impression which without them would have forthwith ended in action is delayed for a season, nay, perhaps even as long, though it may be in a declining way, as the structure itself endures; and with the introduction of this condition of duration come all those important effects which ensue from the various action of many received impressions, old and new, upon one another.

This internal origination of new results through the interaction of impressions retained in the registering ganglia is too important a phenom-

enon to be passed lightly by, more especially when we consider the surprising results to which it eventually leads in the higher forms of life. I shall therefore, without any apology, digress briefly for the sake of illustrating my meaning, by showing how, even in the material world, from conditions which are as fixed as fate, through interaction of consequences variable results arise.

Illustration of the production of variable results by invariable causes.

The laws of nature, being founded on pure reason, are absolutely unchangeable. Of the things which are presented to our contemplation, they alone are invariable. Material substances of every kind wear by time, and exhibit incessant alterations, and this the same whether they are of a terrestrial or a celestial kind. There are tides, eclipses, seasons, births, deaths. Throughout the universe there is no monument that retains its primordial condition; for all material aggregations are only forms, and every form, in the process of time, must perish. There are changes of the surface of the earth, changes in its position as to the sun, changes in the places of systems of worlds as to one another. Every thing is at every moment in motion; but in the midst of all, every law of nature, as, for example, the law of gravitation, endures without variation for an instant, and is never for an instant suspended.

This invariability of natural laws from age to age, even under circumstances in which we might suspect a change, is illustrated by the parallel which may be traced between the development of the most recent embryos, as of man, and those of the ancient geological times, or between human development and that of the whole animal series. In all these cases such a phenomenon is never witnessed as that of a part springing from nothing: it comes out of something existing before, and exists as a consequence of some preceding act. The order in which part arises from part is the same now as it has been in all times—the same in organisms which are most distinct from each other in structure or position in the natural scale; and thus we see that development is not only the consequence of law, but of law which is unchangeable and universal in its application.

As with these phenomena of development and all natural facts, so with the operations of the mind. There is no such thing as a spontaneous or self-originating thought. Every intellectual act is the consequence of some preceding act. It comes into existence in virtue of something that has gone before. Two minds constituted precisely alike, and placed under the influence of precisely the same external physical circumstances, must give birth to precisely the same thought. Such is plainly the consequence of that invariability and universality of the laws of nature on which I have been insisting, which is illustrated by the fact we so often witness in our daily affairs, and strikingly in the case of philosophical discoveries, the same idea occurring to many persons at the same time.

It is this sameness of action to which we allude in that popular expression, common sense—a term full of meaning. In the origination of a thought there are two distinct conditions involved—the state of the mind as dependent on antecedent impressions, and the existing physical circumstances. The brain is the instrument on which external circumstances play; but in the same manner that the course of time presents us with natural vicissitudes, such as night and day, the seasons, the tides, spring and neap, with their ebb and flow, variations of events may ensue, notwithstanding the fate-like aspect of the acting law, and this through the interaction of consequences. So the earth revolves round the sun as a consequence of gravity, and for the same reason does the moon revolve round the earth; for the same cause do the tides flow and ebb in the sea; yet there will be spring tides when the sun and moon draw in one direction, and neap tides when they draw in opposite ways. Out of the invariable the variable may therefore arise.

Illustration of registering ganglia in insects.

To return from this digression to the phenomena displayed by registering ganglia, in continuation of the views offered, I may present as an example the manner in which I should be disposed to regard in this respect the entire nervous system of the articulata. Constructed as these animals are upon an axis, the nerves which are given off from the ganglia upon that axis right and left, a pair for each segment, are primarily purely automatic, and act therefore primarily in a purely reflex way; an impression made on the peripheral extremity of one of their centripetal fibres is conducted to the ganglion, passes through it, escapes along the centrifugal fibre, and a motion occurs. But the whole influence is not thus promptly disposed of. A part of it is conducted by commissural strands to the cephalic ganglia, and there held in reserve. And the same thing holds good for every one of the ganglia of the ventral cord, so that for them all the cephalic become a point of common convergence, or, in my view, the common register for them all. Here, at this focal point, are stored up the relics of whatever impressions have been made upon the common peripheral nerves, and here are received those which are brought from the structures of special sense—the visual, the auditory, the olfactory, if any. There does not, then, appear any great difficulty in explaining the well-marked deviations from automatism which these animals may present.

Function of the cephalic ganglia.

Nerve centres can not act except by oxidation.

The action of every ganglionic mechanism depends upon the existence of certain physical conditions, among which, as being of paramount importance, one may be discerned. It is the due supply of arterialized blood. If this be stopped but for a moment, the nerve mechanism loses its power, or if diminished, the display of its characteristic phenomena correspondingly declines. If, on

the contrary, the supply be unduly great, or its oxidizing power artificially increased, there is a more energetic action. This latter condition of things is presented in the earlier stages of the respiration of protoxide of nitrogen, an increased muscular power, and an exaggeration of the processes of intellection. The opposite state is witnessed when carbonic acid, more or less dilute, is breathed, from that blunting of the intellectual faculties and indisposition for muscular exertion which is felt in ill-ventilated apartments where carbonic acid is permitted to accumulate, to the profound torpor and insensibility experienced when it is in a more concentrated state. These exaltations and depressions of the capabilities of the nervous instrument are, therefore, clearly of a chemical kind, and may be produced artificially and at pleasure by the respiration of appropriate gases or the administration of certain drugs. Nay, even the accumulations of the effete products of the economy are sufficient to give rise to such diminutions of power, as we see when bile or urea is permitted to accumulate in the blood. The therapeutical and toxicological influences of certain medicaments are illustrations of these principles. Of such substances, some act on the sensorial and some on the motor powers.

Necessity of repair and rest.

The copious distribution of arterial blood to the nervous centres indicates that they undergo a rapid waste. That supply can not be for the mere purposes of growth alone, since, when once maturity is reached, the nervous mechanism presents but little expansion. The provision for nutrition assures us that that action must be rapidly going on; but the equilibrium of the system betrays that such nutrition is not for development, but for the repair of waste; and, indeed, this waste proceeds at such a rate that there arises in some portions of this system a necessity for periodic repose, a time for the restoration of the parts. If any arguments were required to establish beyond dispute that such a disintegration of the material of the nerve centres does occur, it would be furnished by an examination of the urine; for, in nervous substance, phosphorus occurring as a characteristic ingredient, it must give rise to the production of phosphoric acid, or salts thereof, in the supposed periods of activity. Moreover, in this metamorphosis of the vesicular structure ammonia must eventually arise, from the cell walls if from no other source, and accordingly we find in the urine that characteristic double salt, the phosphate of soda and ammonia. The amount of these alkaline phosphates has long been known to be in proportion to the activity of the nervous system, particularly in the case of individuals, such as clergymen, whose mental powers are taxed unduly at stated intervals. The general fact that the degree of energy which this system exhibits is dependent on the activity of respiration in different tribes of life might be established from many familiar instances.

Destruction of nervous material is in proportion to nervous activity.

More precise ideas would be arrived at regarding the waste of the nervous mechanism if we possessed a more accurate knowledge of its chemical constitution. The examinations hitherto made are far from agreeing with one another, and this, to a certain extent, is due to the difficulty of obtaining the true nervous tissue in an isolated state, or unmingled with other intervening structures. The following tables will give, however, a general idea of its composition at different periods or in different conditions.

Composition of nervous material.

Analysis of Brain of different Conditions of Life. (*From L'Heritier.*)

	Infants.	Youths.	Adults.	Aged.	Idiots.
Water	827.90	742.60	725.10	738.50	709.30
Albumen	70.00	102.00	94.00	86.50	84.00
Fat	34.50	53.00	61.00	43.20	50.00
Osmazome and salts	59.60	85.90	101.90	121.80	148.20
Phosphorus	8.00	16.50	18.00	10.00	8.50
	1000.00	1000.00	1000.00	1000.00	1000.00

Composition of Spinal Cord of Adult. (*From L'Heritier.*)

Water	710.50
Albumen	73.00
Fat	82.50
Osmazome	115.00
Phosphorus	19.00
	1000.00

Analysis of Medullary and Cortical Substance of Brain of Idiot. (*From Lassaigne.*)

	Cortical and Medullary together.	Cortical.	Medullary.
Water	770.00	850.00	730.00
Albumen	96.00	75.00	99.00
Colorless fat	72.00	10.00	139.00
Red fat	31.00	37.00	9.00
Extractive, lactic acid, and salts	20.00	14.00	10.00
Phosphates of lime, magnesia, and peroxide of iron	11.00	12.00	13.00
	1000.00	998.00	1000.00

From which it would appear that the percentage of water is greatest in the early periods of life, and that of phosphorus in the adult. Attention may also be drawn to the fact that the percentage of phosphorus in the brain of idiots is very low. It also appears that the constitution of the white and gray portions of the brain is different, as might have been anticipated from their appearance, the color of the latter being due to a brown fat. By some it is supposed that the non-saponifiable fat cholesterine arises as a product of waste, and that the phosphorized oils, as they are termed, constitute the white enveloping cylinder known as the white substance of Schwann, and that the interior cylinder is a nitrogenized but non-phosphorized body; but there are reasons for suspecting that the white substance of Schwann is a non-phosphorized fat, and that the axis cylinder contains the phosphorus in an unoxidized state, probably as a highly phosphorized protein body. Every thing seems to in-

dicate that Schwann's substance only discharges the physical duty of an isolator. The coincidence between the varying activity of the nervous mechanism and the varying quantity of oxidized compounds of phosphorus in the urine indicates in a significant manner that this chemical element bears something more than a passive relation to the processes going forward; and its known occurrence in the vesicular structures, together with its extraordinary chemical relations, would prepare us to expect that it is, in reality, intimately concerned in all these phenomena.

Composition of vesicular matter.

Vesicular nervous material contains much less fatty matter than the tubular, but much more water. Thus Hauff and Walther found in the gray substance of the brain from 85 to 86 per cent. of water, and only from 4.8 to 4.9 of fat; but in the corpus callosum they found 70.2 per cent. of water, and from 14.5 to 15.5 of fat. From such facts it would appear that the presence of fat in nervous material is functionally connected with its property of conduction or transmission of nervous influence. In the brain of a child which died at birth, Schlossberger found that the corpus callosum contained as much water as the gray matter, and that, compared with the brain of adults, that of new-born infants is richer in water and poorer in fat. Von Bibra ascertained that, within certain limits, the quantity of fat is constant in the brain; that a diminution or increase of fat in other parts of the system is not accompanied by any change in the quantity of brain-fat; that the proportion of fat in the brain of man, other mammals, birds, amphibia, and fishes, diminishes in the order in which their names are here mentioned; that the medulla oblongata contains the largest percentage of fat; that the quantity of brain-fat in old men is a little less than that of adults in the prime of life. He also concludes that the amount of phosphorus in brain-fat is nearly the same in man, other mammals, and birds; that its percentage in the brain of the insane does not exceed the mean amount; that the vesicular matter contains more phosphorus than the white; and that there is no special connection between the intelligence and the amount of phosphorus; that the amount of fat in the brain of the fœtus is much less than that of the adult, the difference being made up by an excess of water, but that a great and sudden augmentation of fat occurs toward the end of fœtal existence.

Mode of repair of nervous waste.

Our attention may next be directed to the methods of repair of the vesicular structures. Their waste, as just established, implies their repair. Here, as in the muscular tissues, the blood-vessels conduct both operations, and the mode of distribution of the capillaries is such as to bring the circulating current into the most favorable position for discharging this duty. The vesicles are included in the midst of a network of capillaries, and it is believed that there is a resemblance between their mode of growth and that of the cells

of the epidermis; that is to say, they arise from nuclei on the spaces which are nearest to the supply of blood, and gradually undergo development as they prepare for connection with the tubular tissue, assuming the place of cells that have discharged their function and are undergoing disintegration. This gradual passing onward and wearing away recalls the changes in the structure of the cuticle.

To two of the substances thus met with in these examinations of the nervous system our attention may be profitably directed. These are cholesterine and phosphorus. Of the former we can not have failed to remark that it is a constant ingredient in the product of the action of the liver. It is a lipoid, and is found in biliary calculi; and though it may be regarded in one sense as an excrementitious body, since it occurs in fæcal matter, yet it also appears as a normal constituent of the blood. It may therefore be inferred, if the opinion of its existence in the white substance of Schwann be correct, that it is one among the various functions of the liver to prepare this body. Of phosphorus it might be said, that it, among the chemical elements, is most strikingly characterized in its active state by the intensity of its affinity for oxygen. On this depends its quality of shining in the dark, a quality which has given it a name; but by many agents, such, for example, as exposure to a particular temperature, and especially to the light of the sun, it may be thrown into a condition so completely passive that its chemical energies disappear. The doctrine that was presented in explanation of the destruction of one part of the system by the air introduced by respiration while another is protected therefrom, as dependent on the allotropic condition of those parts, is presented here again in discussing the destruction and repair of the nervous tissue; for it is only when it is ready to be removed that the phosphorized constituent assumes the active state, and in so doing gives rise to the development of force. On this view, it would appear that such phosphorized compounds are obtained from the vegetable kingdom in the food in a passive state, the tissues of plants having deoxidized them under the influence of the sunlight, which simultaneously has thrown them into the condition of inactivity, and perhaps it is the assumption of that very condition that is the fundamental cause of their deoxidation.

Cholesterine and phosphorus.

By the aid of the conclusions to which we have come respecting the function of nerve-tubes and vesicles, as betrayed by their anatomical structure, we shall not have much difficulty in explaining the offices of nervous arcs presently to be described. The results at which we thus arrive, from a consideration of those cells, are singularly fortified by the electrical experiments of Galvani, Volta, Nobili, and especially those of Volkmann. Among these, the three following are of primary importance:

Functions of nerve-cells and ganglia considered electrically.

Volkmann's results.

1st. When a continuous electrical current is passed along a centrifugal nerve, contraction of the muscles which that nerve supplies takes place, and continues as long as the electric current passes, without relaxation, but ceases the moment the current is stopped.

2d. When a continuous electric current is passed through a ganglion, contraction of the muscles supplied by the centrifugal nerves of that ganglion ensues. These contractions do not alternate with relaxation, and on stopping the current the contraction does not cease as in the preceding case, but is continued for a period of time.

3d. When a continuous electric current is passed down a centripetal nerve, muscular contraction of the parts supplied by the corresponding centrifugal nerves occurs, and these contractions alternate with relaxations.

In view of these facts, we are brought to two conclusions: First, that there is a property in the ganglion which enables it to hold in reserve a portion of the influence brought into it, so as to keep up the action for a period of time after the original disturbing causes have ceased. Second, that the structure of the ganglion is such as to permit the escape of the coming influence by lateral ways, either periodically or otherwise, and so to produce from a continuous influence an intermitting effect.

Recalling the fact that a ganglion is made up of nerve-tubes and vesicles conjointly, these electrical results must find their solution in the elementary structure of the ganglion, that is to say, in its vesicular portion; for it is not to be supposed that a current of electricity, such as we are here considering, would ever have an opportunity of escaping from the axis cylinder along which it passes. The isolating quality of the white cylinder of Schwann would prevent any such effect. It is not necessary that we should embarrass ourselves here with the fact that electric currents of sufficient intensity could make their way out from the interior channel in spite of its insulating investiture, since it is only with those of a far less power that we have to deal. Arrived in the vesicle, the current at once diffuses itself throughout the granular material, just in the same manner that it would diffuse throughout a spherical conducting mass if brought to it by a wire, and escape therefrom through any number of similar wires that might chance to be in contact with the conducting mass beyond; and though the main body of the current would, as may be readily proved, under these circumstances move in a direct line from the point of entry to the point of exit, there would be nevertheless a diffusion of part of it through the conducting mass, no portion thereof remaining unaffected. In a good conductor, such as a metal, this laterally diverging current would instantly escape, but the case becomes very different in the less perfectly conducting material, the granular substance within the cell. As in the secondary piles of Ritter, which, when

brought into contact with an active voltaic circle, participate in all its qualities, physiological and chemical, give shocks, produce decompositions, and continue to do so for a time after the original influence has ceased, so a similar conservation occurs in the interior of the vesicle; and this I consider to be the consequence of the difference of structure of the fibrous axis cylinder and the granular vesicle contents. The continuous lines along which the influence has been coming terminate on reaching the vesicle, and are replaced by a divided and inferior conveying structure, a structure which recalls at once the secondary piles of Ritter just alluded to.

Analogy with the secondary piles of Ritter.

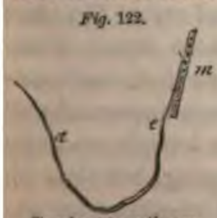
We may therefore truly say that these electrical experiments offer a striking confirmation of the truth of the conclusions to which we have come from the study of the anatomical structure of a nervous arc. They assure us that a vesicle, and therefore a ganglion, has a double office to perform, the stopping, reserving, storing up a part of the influence which is brought to it, and also the conveying of that incident influence into many new channels. These conclusions are altogether independent of any conception of the nature of the nervous agent: it may be identical with, or allied to, electricity, or it may be a totally different principle. It is not that question which we are concerning ourselves with now. We are dealing with structure and its interpretation. Whatever our views may be of the nature of innervation, we shall find ourselves constrained to infer that the delays, divergences, detentions, and subsequent surrender, the opportunity of diverging from one into many new channels, or conversely the convergence from many lines of entry into a single one of exit, with all the accompanying interferences and reactions, must be common to both the electrical and the nervous agent, for they depend, not upon the qualities of those principles, but upon the anatomical structure through which they are passing.

Coincidence of anatomical and electrical examination.

With these remarks I proceed to an exposition of the typical construction of the nervous system, pointing out its successive complications. The hypothetical diagrams which I shall now present are chiefly for the sake of impressing the conclusions at which we have arrived from a consideration of the structure of the nervous elements, fibrous and vesicular, the experimental determination of those functions, and their electrical phenomena. That these diagrams are, however, somewhat more than imaginary sketches, will be obvious from a consideration of the nervous mechanism of the articulata, which offers striking illustrations of them.

Hypothetical illustration of nervous mechanism.

Fig. 122.



Simple automatic arc.

The simple automatic nerve arc, *Fig.* 122, consists of an afferent or centripetal fibre, *a*, connected continuously with an efferent or centrifugal fibre, *e*. An

impression made on the free extremity of a instantly produces a contraction in the muscular fibre m, which the efferent branch e supplies. The whole force is at once consumed, no portion of it remaining.

Fig. 123.

Simple cellated arc.

The simple cellated nerve arc, *Fig.* 123, consists of a centripetal fibre, a, which, receiving impressions on its free extremity, conveys them to the vesicle v, from which the influence passes forward along the centrifugal fibre e, causing the muscular fibre m, which the nerve supplies, to contract. An impression made at a therefore produces motion at m. The action is purely automatic, and a part of the force is stored up or remains in the vesicle.

In the figures here given, the centripetal and centrifugal fibres are represented apart. In fact, however, they may be considered as bound together, for the sake of compactness, without there being any fusion or coalescence of structure or functions. It is also to be understood that the free extremity of the centripetal fibre is connected with some special mechanism adapted to the influence it is to receive. Thus its axis cylinder may be naked, or connected with a vesicle, or with an apparatus for the reception of light, or sound, or heat, or pressure, &c.

Multiple automatic nerve arcs arise from an arrangement of many such simple arcs in succession longitudinally, as in *Fig.* 124, or it may be in a circular order. The former case is presented in the articulata, the latter in the radiata. Each symmetrical portion of the animal has its own nervous arc, but as such symmetrical portions are not destined to live an independent life, but to act in unison with the others, a necessity arises for each arc to be brought in relation and maintain a connection with the others, and this is done by extending from ganglion to ganglion fibres of communication, c, c, which may here be called commissural fibres. So the circle of ganglia which surrounds the mouth of the radiata is not a circular arrangement of isolated ganglia, but a ring of ganglia and commissures conjointly. Where the nervous system is planned symmetrically on the two sides of the mesial plane, the ganglia are commissured across the plane to insure a reciprocity of action. In the molluscs, whose organs of animal life show this bilateral symmetry, and which have three such ganglia, the cephalic, pedal, and parieto-splanchnic, each is commissured with its colleague on the other side of the plane, or they are brought up to the plane and juxtaposed, the commissure then disappearing, but their bilobed aspect betraying their separate construction. The coalescence fre-

Fig. 124.

Multiple nerve arcs.

Commissural fibres.

Fig. 125.

Pairs of arcs commissured.

quently becomes more intimate, and all traces of the original double construction disappear.

The letters remaining the same as in the preceding diagrams, *Fig.* 125 represents the manner of commissuring across the mesial plane.

As illustrations of the manner in which these mechanical principles are carried out, the following figures are given.

Illustrations from various animals.

Fig. 126, nervous system of the larva of the sphinx ligustri, showing the successive arrangement of multiple nerve-arcs from 1 to 11, commissured with one another, and all with the cephalic ganglion 17, which is their common register.

Fig. 127, the pupa condition of the same insect, and *Fig.* 128 the imago. (Newport.)

Fig. 129, nervous system of the asterias, in its elementary parts. It consists of a series of five ganglia, *g*, *g*, circularly arranged round the mouth of the animal, and giving forth to each ray a pair of nerves. (Tiedemann.)

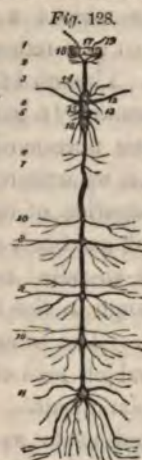
Fig. 126.

Nervous system of larva of sphinx ligustri.

Fig. 127.

Nervous system of pupa of sphinx ligustri.

Fig. 128.



Nervous system of imago of sphinx ligustri.

Fig. 129.

Nervous system of asterias.

Fig. 130, nervous system of patella: *l*, *l*, lateral ganglia, commissured with the cephalic, which is between them; *t*, the transverse or subœsophageal ganglion, commissured in like manner. (Cuvier.)

Fig. 130.

Nervous system of patella.

Fig. 131, nervous system of sepia octopus: *c*, cephalic ganglion; *o*, *o*, optic ganglia; *g*, subœsophageal ganglion; *l*, *l*, lateral stellate ganglia; *a*, abdominal or visceral ganglion. (Cuvier.)

Fig. 131.

Nervous system of octopus.

Fig. 132.

Nervous system of aplysia.

Fig. 132, nervous system of aplysia: *a*, anterior ganglion; *c*, cephalic; *l*, *l*, lateral; *g*, abdominal.

Function of commissures.

In the mechanical interpretation of the nervous system, the action of commissural strands is a point of primary importance. It may be said that they are for the purpose of drawing off from the nerve arc a part of the influence which is coming along the centripetal fibre, and directing it into a new channel. If such coarse illustrations are permissible, the vesicles act like a three-way cock, or perhaps like a piece of looking-glass with a part of the foil removed from its midst; a beam of light impinging upon it is in part reflected, and part escapes behind through the uncovered space. Though I have described the simple cellated nerve arc as containing essentially a ganglion or vesicle, it is not to be supposed that such a structure necessarily impresses any change on the incoming influence. Since, if we irritate a centripetal fibre, muscular motion may ensue from propagation of that irritation through the ganglion, and if we irritate a centrifugal fibre, muscular motion equally ensues, it is quite clear that in the so-called action of reflection by the ganglion there is, in reality, no change in the influence which has been brought along the centripetal fibre. The same impression on any part of the nervous arc, no matter on which side of the ganglion it may be made, will produce the same muscular result.

Act of reflection.

Such considerations therefore lead us to suspect that nothing takes place in the ganglion which justifies such an expression as "act of reflexion" or "reflex action," terms which convey an idea that the influence which passes in the two branches of the nerve arc is different, the difference having been established or brought on by the ganglion. They confirm the opinion that the ganglion has, for one of its primary duties, the function of permitting an escape of the influence passing in the interior of the centripetal fibre into new channels for the establishment of new results.

Instantaneous action of the simple arc.

In the simple automatic nerve arc the impression and the effect are instantaneous. An irritation of the centripetal branch produces, without any sensible interval of time, muscular contraction through the action of the centrifugal branch, and that contraction ceases the moment the impression is over. But the opening out of the nerve arcs by the introduction of a vesicle permits a part of the influence, whatever it may be, to be drawn off, and this, now passing along the commissural line, may be dis-

Reserved action of cellated arcs.

posed of in two different ways: 1st. The influence thus drawn off may be instantaneously consumed or utilized by exciting, through adjacent simple arcs, synchronous movements; or, 2d. It may be held in reserve for future use by being carried along the commissure to a receiving, or, as I may term it, registering ganglion.

This, therefore, introduces a more complex mechanism, which may be designated as,

The registering nerve arc, the typical construction of which is represented in *Fig.* 133. In this we have the centripetal, *a*, and centrifugal fibre, *e*, as before, in connection with their central vesicle, *v*; but, passing from that central vesicle, a commissural fibre, *c*, offers a channel of escape of a part of the influence which so reaches the registering ganglion, *r*, and makes a permanent impression upon it by disturbing its condition physically or chemically; and, since many nervous arcs may be thus commissured upon the same registering ganglion, it thus becomes for them all a central point of deposit and a centre of common action. And in this manner not only is a temporary influence converted into a permanent impression, but, from the interaction of such impressions upon one another, new and variable results arise. Some illustrations were given a few pages back of the development of the variable from the invariable in the case of certain ordinary physical phenomena, and these may be profitably referred to again.

Fig. 133.

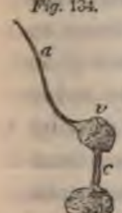
Registering nerve arc.

Registering nerve arcs.

Variable effects arise from invariable impressions.

A modification of the registering nerve arc is presented in *Fig.* 134, which exhibits the suppression of the centrifugal branch, the whole influence received passing along the commissural line to the registering ganglion. This condition of things may occur when the centripetal branch at its free extremity is involved in a mechanism of special sense, olfactive, ophthalmic, or auditory. No part of the impression thus received is necessarily expended at once; the whole may be thus retained, and utilized at a future time. The introduction of the registering ganglion is thus the introduction of the element of time in a living mechanism. In the lower forms of arc an impression is instantaneously expended, in this it is preserved.

Fig. 134.



Suppression of centrifugal branch.

Suppression of centrifugal branch.

The common centre or register of whatever impressions have been received by the special sense instruments, olfactive, ophthalmic, or auditory, as well as impressions of a general tactile kind, is doubtless to be properly regarded as the sensorium. Though animals constituted on this type accomplish many variable actions, that variabil-

The sensorium.

ity is essentially and purely automatic. As such may be regarded the instinctive actions of bees, any two of which, if placed under the same circumstances, act with undeviating certainty in the same way. The whole career of life of one of these insects is the whole career of any other. They build their combs now in the same way that they did a thousand years ago; their daily doings are the same as they have ever been. Except as respects a particular, hereafter to be pointed out, they may be regarded as automatons.

Effect of the introduction of a registering ganglion.

The introduction of a registering ganglion necessarily gives rise to an extension of the physical relations of an animal by connecting its present existence with antecedent facts, for the ganglion at any moment contains the relics of all the impressions that have been made on it up to that time, and these exert their influence on any action it is about to set up. In virtue of them, the nervous mechanism has now the power of modifying whatever impressions may be made on its centripetal nerves, and, within certain limits, of converting them into different results. Yet still the automatic condition is none the less distinct, and still the immediate source of every action is to be found in external impressions.

Sensory and motor lobes.

An increasing complexity of nervous structure is next evidenced by a division of the registering ganglion into two portions, which, with some incorrectness, may be designated sensory and motor lobes, a division which is preparatory to, and, indeed, obviously connected with, the introduction of a totally new method of action and source of power.

In *Fig.* 135 we have an ideal sketch of this new condition of things. The letters used in the preceding cases, in this refer again to the same parts. But now it is seen in addition that the registering ganglion has assumed a bilobed aspect, *s m*, the letters respectively indicating its sensory and motor portions, or, to use the language of human anatomy, a thalamus and corpus striatum. From these there branch off commissural lines, radiating to a hemispherical collection of vesicular matter, *c c*, the representative of a cerebrum.

Fig. 135.

Influential arc.

The influential arc.

Assuming the registering ganglion as a centre, the arc-like arrangement on either side of it is symmetrical, as is shown in *Fig.* 135. And since it will facilitate our consideration to introduce here distinctive terms, I shall designate the external arc, which is in relation with the external world, as the automatic arc, and the inner one, which is in relation with the cerebrum, the influential arc.

Throughout this work I have constantly assumed the existence of an intellectual principle, spirit, or soul, whose links of connection with the

external world are the sensory ganglia and the cerebral hemispheres. We may now profitably inquire whether any argument in behalf of the existence of such an agent may be gathered from the anatomical and physiological facts just presented, or whether we must assume it as a postulate, relying for proof on evidences of a totally different character to those which are presented by the science now engaging our attention. It is to be greatly regretted that evidence drawn from structural arrangement has hitherto, by very high authority, either been totally cast aside or held in very light esteem. It is still more deeply to be regretted that those who should have known better have conceded the argument that from no consideration based upon anatomical or structural arrangement could proof be obtained of the existence of an immaterial principle. Even by such, the study of physiology has been designated as leading to materialism, and, with an injustice which can not be too emphatically reprobated, the scandal has often been quoted, that where there are three physicians there are two atheists.

Evidence of the existence of the soul derived from cerebral structure.

But what if it should turn out that, from the study of the cerebral mechanism, distinct proof can be obtained on this point—proof of just as cogent a nature in support of the doctrine of the existence of the soul as that which we have of the existence of the external world, and of precisely the same character? Without, therefore, occupying myself with such other evidence as might be drawn from theological or metaphysical sources, and which are therefore extraneous to the object of this work, I shall proceed to point out such considerations as naturally offer themselves to our minds when we recall the general structure of the nervous apparatus. Repeating, therefore, such facts as may be necessary for the proper understanding of this interesting argument, I present it as follows:

The simple cellated nervous arc consists essentially of these portions, a centripetal fibre, a vesicle, and a centrifugal fibre; the centripetal fibre may have at its outward or receiving extremity vesicular or cellular material. Thus constituted, this mechanism is ready to receive external impressions, which, if such language may be appropriately used, are converted or reflected in part by the ganglion into motions, and the residue retained. But the arc, viewed by itself, is a mere instrument, ready, it is true, for action, but possessing no interior power of its own. It is as automatic as any mechanical contrivance in which, before a given motion can be made, a certain spring must be touched.

Automatic mechanism of a nerve arc.

The essential condition of the activity of such a nervous arc is therefore the presence and influence of an external agent—a something which can commence the primitive impression, for without it the mechanism can display no kind of result. More-

Requires an external agent for action.

over, there must be an adaptation between the nature of that agent and the structure thus brought in relation with it, as is strikingly illustrated by each of the organs of sense. Thus the peripheral extremities of the fibrils of the optic nerve are involved in a combination of a purely physical kind, having relation to the properties of light: the convex surface of the cornea, the unequicurved lens, the diaphragmatic iris, the interior investiture of black pigment, these are all structures the object of which we clearly understand. We know that the rays of light must undergo refraction at the curved surfaces upon which they are incident, and depict the images of external forms on the retina or black pigment, the iris expanding or contracting, as the case may be, to regulate the entrance of the light. So completely do we admit this principle of an adaptation of structure to the nature of the agent which is to set it in activity, that in this particular instance, without any hesitation, we class the eye among optical instruments, and include its description in our optical treatises. But in the same manner that, starting from the well-known properties of light, we advance to the explanation of the uses of each of the various parts of the eye, there can be no doubt that the converse of this method of reasoning would be possible to an intellect of sufficient power, who, from a full consideration of the structure of the eye, might determine the properties of light, guided in doing this by the principle that there must be an adaptation between such structures and such properties; and, in the same manner, a man deaf and dumb, but of an intellect of great capacity, might doubtless, from the critical study of the construction of the ear, determine the nature of sounds. Nay, even more, it is not impossible that he should be able to compare together the physical peculiarity of the movements which constitute light or sound respectively, and to demonstrate that these originate in normal, and those in transverse vibrations.

Adaptation between the agent and the mechanism.

So, therefore, these problems present themselves under a double aspect, and are capable both of a direct and an inverse solution: Given the nature of light, to determine what must necessarily be the construction of the organ of vision; or, Given the construction of the eye, to determine what is the nature of light; and the same might be said of the organ of hearing. This inverse method of treating natural agents is still in its infancy, because of the extreme imperfection of our knowledge; but doubtless what has been said will recall to the mind of the reader the parallel example which is furnished by astronomy, and which, within a few years past, has yielded such a splendid result. The mass of a planet being known, the perturbations which it can cause in another are capable of direct computation, but it was reserved for Leverrier to discuss the inverse problem, and from the perturbations to find the place of the planet. The discovery of Neptune was the result.

Nature of inverse physiological problems.

Now the problem we are dealing with is of this inverse kind. It may be stated, Given the structure of the cerebrum, to determine the nature of the agent that sets it in action. And herein the fact which chiefly guides us is the absolute analogy in construction between the elementary arrangement of the cerebrum and any other nervous arc. In it we plainly recognize the centripetal and centrifugal fibres, and their convergence to the sensory ganglia, the corpus striatum and optic thalamus; we notice the vesicular material at their external periphery as presented in the convolutions of the human brain; and if in other nervous arcs the structure is merely automatic, and can display no phenomena of itself, but requires the influence of an external agent—if the optical apparatus be inert and without value save under the influences of light—if the auditory apparatus yields no result save under the impressions of sound—since there is between these structures and the elementary structure of the cerebrum a perfect analogy, we are entitled to come to the same conclusion in this instance as in those, and, asserting the absolute inertness of the cerebral structure in itself, to impute the phenomena it displays to an agent as perfectly external to the body and as independent of it as are light and sound, and that agent is the soul.

External influence required for the influential arc.

The soul.

It would not comport with the object of this work to pursue this argument in its details, yet I can not forbear observing that, even so far as we have already advanced, the point which, after all, is of the utmost importance, is completely attained. Those who have accused physiology of tending toward materialism have never duly weighed the accusation they make, and certainly have never understood the nature of the arguments it can present; for such as the one here imperfectly set forth, from their tangible nature, will commend themselves to many minds who do not appreciate the strength of purely metaphysical arguments, and herein they may become subservient to the highest and most enduring interests of our race.

And thus it may be proved that those actions which we term intellectual do not spring from mere matter alone, nor are they functions of mere material combinations; for though it is indisputably true that the mind seems to grow with the bodily structure, and declines with it, exhibiting the full perfection of its powers at the period of bodily maturity, it may be demonstrated that all this arises from the increase, perfection, and diminution of the instrument through which it is working. An accomplished artisan can not display his power through an imperfect tool, nor, if the tool should be broken, or become useless through impairment, is it any proof that the artisan has ceased to exist; and so, though we admit that there is a correspondence between the development of the mind and the growth of the body, we deny that

Independence and immortality of the soul.

it follows from that, either that the mind did not pre-exist, or that the death of the body implies its annihilation.

Opinions respecting the aspect of the soul entertained by different nations.

If it fell within the compass of our plan, we might proceed to consider how far, since the mind can act upon external nature through the intervention of the bodily mechanism, the converse is possible; how, since the face of things around us can be changed by our voluntary exertions, the intellectual faculties may be changed by the action of external nature through the bodily mechanism. And since we have established the existence of the intellectual principle as external to the body, we might proceed, for now we are entitled so to do, to reason respecting its nature from the phenomena it displays. I do not, however, propose to enter on those considerations now, and shall close these remarks with a reference to some doctrines proposed by the most highly-advanced and intellectual portions of the human family.

It is said that the spirit of man is created in the image of God, an observation strikingly illustrated by the fact that, as regards both, two essentially different doctrines have been held—the pantheistic, by some of the most highly advanced of the Asiatics, and the anthropomorphic, by the Europeans. The pantheistic supposes the human soul to be a part of the Deity, and therefore devoid of form; the anthropomorphic as having the likeness of the body. The Asiatics, then, regarding the Deity as a principle diffused in and throughout nature, consider the spirit of man as a part or portion thereof, and often use such illustrative allusions as those of a drop of water in the ocean, a spark of a universal and vital flame; or, if they do not accept this view of a oneness in the nature of spirit and Deity, they regard the former as arising in some manner from the latter, just as waves may exist upon the sea, or sounds may arise in the air. They believe that at death there is, as it were, a reunion of the part with the whole, as every drop of water sooner or later finds its way back to the sea, or waves become quiet and disappear, or sounds die away in the air.

But with European nations there has been, from their very infancy, a tendency to the anthropomorphic conception. The barbarians before the Roman empire, in their legendary fables, accepted the idea of disembodied spirits under the shape of men, and through the intervening ages up to our own times, such notions, under various forms, have been held. The rural populations entertain an undoubted faith in fairies and ghosts, so that it might be asserted that this manner of viewing the thing is almost natural to us. We instinctively represent to ourselves in this way the immaterial principle, and in the case of each individual expect a correspondence between it and his bodily form. Whatever may be our authority for arriving at such a conclusion, there can be no doubt that it

so specializes and intensifies our ideas, and is so connected with many of our most highly cherished recollections, that, even were the evidence in its behalf far weaker than it actually is, we should look without favor on any attempt to invalidate the doctrine, and, if forced to do so, should abandon it with regret. The pantheistic is a grand but cold philosophical idea; the anthropomorphic embodies our recollections, and restores to us our dead. The one is the dream of the intellect, the other is the hope of the heart.

Imperfection of metaphysical investigations.

We have thus traced out the essential elements of the nervous machine in its highest complexity, and shown its gradual rise from the purely automatic to the influential. We may therefore comprehend the difficulties under which metaphysicians labor, who confound all these parts and all these functions together, and pass over as of no account the guiding indications which are furnished by the study of structure. It is not difficult for the physiologist, enlightened by the knowledge he possesses, to recognize the various points at which these philosophers go astray—the point at which their theories cease to be representations of the truth. He acknowledges the existence of an external nature, and equally the existence of an immaterial spirit, and to their action on or relation to each other he traces the resulting phenomena. He admits that, among certain classes of life, every motion and every sensation is due to external nature alone, but to these purely automatic groups man does not belong. He repudiates the doctrines of the idealist, because, though they may maintain themselves in the uncertainties of metaphysical argument, they are dissipated at once in the more severe trial of anatomical discussion.

Provision in the nervous system for ideas of space and time.

There are two fundamental ideas essentially attached to all our perceptions of external things: they are SPACE and TIME, and for these an early provision is made in the nervous mechanism, while yet it is in an almost rudimentary state. The development of the eye and the ear, as we shall more particularly find when we come to the description of these organs, is for this purpose. In a philosophical respect the eye is the organ of space, and the ear of time; the perceptions of which, by the elaborate mechanism of these structures, become infinitely more precise than would be possible if the sense of touch alone were resorted to. The indications thus gathered are transmitted by the optic and auditory nerves respectively to the brain.

Objective, subjective, and impersonal operations.

In its highest condition of development, the nervous mechanism has a threefold operation, objective, subjective, and impersonal. Objective ideas arise in external facts; subjective in registered impressions; the impersonal, as, for example, the abstract truths of geometry, issue of pure reason, and are therefore to be attributed to the essential nature of the soul. Of these three elementary constituents all human knowledge consists.

Illustrations of the vestiges of impressions.

As respects subjective or registered impressions, a few remarks may be here made. There can not be a doubt that the registry of impressions involves an actual structural change in the ganglion, which is of a permanent character. These changes may be rudely and imperfectly illustrated by experiments, such as I published years ago, of which the following may be taken as examples: If, on a cold, polished piece of metal, any object, as a wafer, is laid, and the metal then be breathed upon, and, when the moisture has had time to disappear, the wafer be thrown off, though now upon the polished surface the most critical inspection can discover no trace of any form, if we breathe upon it a spectral figure of the wafer comes into view, and this may be done again and again. Nay, even more; if the polished metal be carefully put aside where nothing can deteriorate its surface, and be so kept for many months (I have witnessed it even after a year), on breathing again upon it, the shadowy form emerges; or, if a sheet of paper on which a key or other object is laid be carried for a few moments into the sunshine, and then instantaneously viewed in the dark, the key being simultaneously removed, a fading spectre of the key on the paper will be seen; and if the paper be put away where nothing can disturb it, and so kept for many months, at the end thereof, if it be carried into a dark place and laid on a piece of hot metal, the spectre of the key will come forth. In the case of bodies more highly phosphorescent than paper, the spectres of many different objects which may have been in succession laid originally thereupon will, on warming, emerge in their proper order.

I introduce these illustrations for the purpose of showing how trivial are the impressions which may be thus registered and preserved. Indeed, I believe that a shadow never falls upon a wall without leaving thereupon its permanent trace—a trace which might be made visible by resorting to proper processes. All kinds of photographic drawing are in their degree examples of the kind. Of the moral consequences of such facts it is not my object here to speak. The world would be none the worse if every secret action might thus be made plain. But if on such inorganic surfaces impressions may in this way be preserved, how much more likely is it that the same thing occurs in the purposely-constituted ganglion! Not that there is any necessary coincidence between an external form and its ganglionic impression any more than there is between the letters of a message delivered in a telegraphic office and the signals which the telegraph gives to the distant station, yet these signals are easily retranslated into the original words—no more than there is between the letters of a printed page and the acts or scenes they may chance to describe, but those letters call up with clearness in the mind of the reader the events and scenes. Indeed, the quickness with which the mind interprets such traces or impressions

Interpretation of such vestiges.

n its registering ganglia is illustrated by the rapidity with which we ather the sense of a printed page without individualizing each of the etters it contains, or as a skillful accountant runs his eye over a long olumn of figures, and seems to come by intuition at once to the correct um. The capability which we thus possess of determining a final perption or judgment of results, without dwelling on the intermediate aces or steps, is also illustrated by our appreciation of music without oncentrating our thoughts on the time and intensities of vibration or inrferences of the notes, though these mathematical relations are at the ery bottom of the harmony; and conspicuously does the Supreme Inlligence, God, reach with unerring truth to every final result without ny necessary concern in the intermediate steps.

From the preceding considerations we may infer that there is a necesary limitation of the amount of impressions capable of being egistered in the organism, and therefore, in this regard, all uman knowledge is finite. Yet its term is much farther off han might at first sight appear. A library of a given size may only be ble to contain a given number of books upon its shelves, but the amount f information it is capable of containing may be made to vary with the ondensation and perspicuity of the books.

Finite nature of human knowledge.

In the hypothetical language of physiology, the nervous centres are poken of as the origin of the nervous influence or force. A lose examination of the phenomena they display leads us, owever, to receive such a doctrine with a certain amount f limitation. Most of the ganglia produce no motor imulses except under the action of external impression, and under the elmentary view we have just presented regarding the function of the rain, the same remark applies even to it, since the immaterial principle, whose instrument it is, must be regarded as an agent distinct from it, nd in that respect external. Indeed, the cases in which the nervous entres seem to display the quality of spontaneously originating force are o few, and in their nature so doubtful, that we are almost entitled to disegard them. For example, the ganglia of the heart are by some upposed to cause, by their own inherent power, the contractions of that organ, which in cold-blooded animals, long after it has been excised, will ontinue its rhythmic motions. But it is far more agreeable to the analgies of the nervous system to regard these cardiac ganglia, not as orignators of power, but as merely depositories, reservoirs, or magazines of t. There is nothing more extraordinary in their ability to keep up the notions of the organ with which they are connected than there is in the ubsidiary spring of a chronometer, which maintains the movement of hat instrument for the period during which the action of the mainspring s taken off while it is being wound up. Yet the mainspring, and the

Conclusion respecting the spontaneous function of ganglia.

subsidiary spring too, derive their mechanical power originally from the force which has wound up the chronometer. In this particular of the storing up of power for its utilization in the time of need, the whole ganglionic or sympathetic system of nerves may be taken as the great example.

Nature of the action of nerve centres.

The conveyance of an impression through the great nervous centres is more complicated than it is through the nerve trunks. It may be conducted, if of sufficient intensity, through one ganglion after another in succession. The intermedium through which this is done is probably the nerve-tubes in a majority of instances, though perhaps, in those cases in which a longer period of time is occupied, it may be rather from vesicle to vesicle than through the tubes. Impressions may be thus transferred from one set of tubes to others, or they may be diffused from a nerve centre to many tubes around, and so produce a wider circle of influence. That transfer of impressions from centripetal to centrifugal fibres which has been previously described as reflex action, though commonly involuntary, may in many instances be governed by a direct exertion of the will. Thus the respiratory movements for the introduction of air may be controlled to a certain extent, as in holding the breath, but this is only during a short time, for the necessity of permitting the normal action to occur presently becomes insuperable. Of reflex actions, the majority are obviously for the accomplishment of some special object so long as the system is in health—they are means for an end; but in diseased conditions they very often occur in an objectless or useless way.

Conveyance of impressions through centres.

Nature of mental emotions.

In its most perfect condition, the nervous system thus consists of two separate mechanisms, the automatic and the influential, and these are so related that they can mutually act on one another. The will can exert a control over the so-called reflecting function of the automatic part, and external impressions which have been received by that part can exert a reaction upon the will. It is in this way that mental emotions may be explained, the power of external influences which antagonize or even overcome the will.

CHAPTER XV.

THE SPINAL AXIS.

Primitive Development of Nervous System.—Its final Condition in different Vertebrates.
The Spinal Cord: its Structure.—Its Membranes.—Its Thirty-one Pairs of Nerves.—Properties of their Roots.—Functions of the Cord.—Bell's Discovery.—Transmission of Longitudinal and Transverse Influences.—Reflex Action of the Cord.—Nature of Reflex Action.—Motor and Sensory Tracts of the Cord.—Summary of its Functions.
The Medulla Oblongata: its Structure and Functions.
The Pons Varolii: its Structure and Functions.
Dr. Carpenter's Views of the Analogy between the Spinal Cord of Vertebrates and the Ventral Cord of Articulates.

WE now commence a more detailed examination of the nervous system, presenting a description of its structure as far as may be necessary for the understanding of its functions. We shall follow the usual division of this subject as adopted by authors. This will therefore lead us to speak in succession of the spinal cord and medulla oblongata, of the sensory ganglia, of the cerebellum and cerebrum, of the nerves generally, and, lastly, of the sympathetic system.

Subdivisions of the subject.

The important position occupied by the nervous mechanism in the animal body will always draw to it the closest attention of the physiologist, and yet it must be admitted that hitherto it is the least advanced portion of the science. If metaphysicians are to be blamed for casting away the advantages which arise from a study of structure, the earlier physiologists were almost equally in error in confining themselves to human anatomy alone. They did this under an impression that there is an essential and intrinsic difference between the functions of this system in man and in the lower animals.

Advantages derived from comparative physiology.

There is an analogy of construction in all the forms of nervous system presented by the different animal tribes, which, in the infancy of the sciences of organization, was attributed to a unity of design pervading the plan of Nature, but which, when seen from a higher and more philosophical point of view, is plainly the necessary result of a universal and unvarying law of development. This conclusion, which, when better understood, is doubtless destined to become one of the most important suggestions ever furnished by science respecting the management of the world, is strikingly enforced by the analogies between the successive transitory stages of development of this system at different epochs in the life of man, and the permanent form it assumes in members of the entire animal series. Since there can

Advantages derived from development.

be no doubt that every animal function, from the automatic motions of the obscurest living form up to processes of intellection of man, depend upon this structure as on an instrument, we may, by a due comparison of the habits, instincts, or other phenomena in such cases with the existing nervous development, arrive at true conclusions of the connection between its structure and its functions. We shall therefore indicate, in a general manner, the order of development of this system in man, and then its permanent stages in the animal series.

Course of development of human nervous system.

The nervous system first makes its appearance in the serous lamina of the germinal membrane and in the midst of the pellucid area as the primitive trace, a delicate and pale-white line rising somewhat above the general surface of the germinal area. This line soon presents a conical aspect; the thicker portion is destined to become the head of the embryo. After a short interval, the membrane is gathered into a fold on each side of the primitive trace, and these folds, advancing toward each other, constitute the dorsal laminæ, which, when their edges have met and coalesced, form a tubular cavity—a rudimentary preparation for the vertebral column. Beneath the tube so arising may be discovered, at this stage, a line of nucleated cells—the chorda dorsalis. As the edges of the dorsal laminæ approach each other, they assume a wavy form, and simultaneously a bending forward or curvature of the embryo occurs, so that the vertebral tube becomes arched. In the middle wavy portion are now to be seen rectangular plates, the elements of the future vertebræ. The coalescence of the middle part of the dorsal laminæ takes place first, the ends as yet diverging in the portions which correspond respectively to the head and the sacrum. The spinal marrow and the brain thus arise at the primitive trace, the brain being a superposed or additional structure to the spinal marrow; for now the wavy edges of the anterior extremity are gradually seen to give origin to three cells by their juxtaposition: 1st. The epencephalon, a single cell, to produce the medulla oblongata: its cavity is to be the fourth ventricle; 2d. The mesencephalon, also a single cell, for the corpora quadrigemina: its cavity is to be the ventricle of Sylvius; 3d. The deutencephalon, a single cell, for the optic thalami: its cavity is to be the third ventricle. Though at first transparent and fluid, the nervous matter becomes by degrees more consistent and covered over with a thin layer of membrane, the indication of its future investitures. The rudiment of an eye, under the form of a protrusion, now appears from the most anterior cell; and in like manner the auditory apparatus emerges from the cell of the medulla oblongata, from the anterior part of which, by the coalescence of a pair of fasciculi which have arisen, the cerebellum begins to form. At this period, through the continued curvature of the embryo, the cell of the corpora quadrigemina has become most anterior.

The origin of the spinal cord and brain is illustrated in the annexed figures from Bischoff. *Fig.* 136 shows upon a dark ground a portion of the germinal membrane, in the midst of which is the area pellucida and primitive trace: *a*, the area pellucida; *b*, the dorsal laminæ; *c*, the primitive trace.

Origin of the spinal cord and the brain.

Fig. 136.

The primitive trace, magnified 8 diameters.

Fig. 137.

Origin of the brain upon the spinal cord, magnified 8 diameters.

Fig. 137, the same at a later stage, preparation for the brain being made. The dorsal laminæ are approaching each other, particularly toward the middle: *a*, the dilated upper extremity or cephalic end, the three cells appearing: the epencephalon, mesencephalon, and deutencephalon; *b*, chorda dorsalis along the bottom of the groove; *c*, rudiments of vertebræ; *d*, lancet-shaped dilatation. In both figures the pale borders along the primitive trace are pellucid nerve substance.

The dorsal cord, which is only a transitory structure, now disappears, the spinal marrow commencing to exhibit a division into four strands, right and left, upper and under. The medulla oblongata flattens next in its upper part, its fasciculi parting from each other; the interval so arising between them is to be the fourth ventricle. The hemispheres now appear as a double cell, the prosencephalon, and as development goes on, they soon exceed the corpora quadrigemina in size, and, as they advance, force these bodies backward and under them.

From this it appears that the type of construction of the nervous system is, that upon the rudimentary spinal marrow a series of vesicles is developed. They constitute eventually the medulla oblongata, the cerebellum, the corpora quadrigemina, the thalami optici, the corpora striata, the olfactive ganglia, and in front of all, but destined to cover the anterior portions over, the hemispheres.

Turning now to the animal series, we find in the lowest members of

Comparative nervous system in vertebrates.

the vertebrata, as in the amphioxus, the spinal cord, medulla oblongata, and the elementary representatives of the sensory ganglia alone, and as, in succession, we pass to the higher ones, we recognize a cerebellum appearing over the medulla oblongata, and cerebral hemispheres over the sensory ganglia. These organs in the upward career become more and more developed, the hemispheres, for example, soon equaling in size the quadrigemina, and then greatly surpassing them, and with this increase of size a higher grade of intelligence is reached. In fishes there are four ganglia, corresponding respectively to the cerebellum, quadrigemina, cerebral hemispheres, and olfactive ganglia. In reptiles the number of ganglia and their order of occurrence is the same, but the cerebral hemispheres have now greatly increased, an increase which is even better marked in birds, for in them the hemispheres have expanded in front so as to cover the olfactive ganglia, and posteriorly the optic, a condition of things analogous to that presented by the human brain at about the close of the third month of fœtal life, and approaching that permanently exhibited by the lower mammals, as, for instance, the marsupials. It is to be understood that what is here spoken of as the hemispheres answers in reality only to the anterior lobe of the cerebrum of man; and as in him, during the fourth and fifth months, the middle lobes are developed in the upward and backward direction from the anterior, and still later the posterior lobes from the posterior of these, the same course is followed in the animal series, the final type of development, the trilobed cerebrum, being only reached by the highest carnivora and quadrumanous animals.

Commencing now more particularly with human nervous anatomy—

STRUCTURE OF THE SPINAL CORD.

Description of the spinal cord.

The spinal cord is placed in the midst of the vertebral canal. In form it is cylindroid, its section being elliptical, the lateral diameter being the long one. Longitudinally it shows two enlargements, one about its upper third, the other toward its termination. Exteriorly it is white, but its section shows a gray substance, arranged in the form of two crescents connected by an isthmus. Above, it is continuous with the brain, which, indeed, is a development upon it, and below it terminates at the cauda equina. Its relative length is much greater in fœtal life, at the third month of which it extends into the sacrum. In adult life it only occupies about the upper two thirds of the vertebral canal; it is generally stated that its termination is about the first or second lumbar vertebra. Moreover, it does not fill the vertebral canal, being, by reason of the transverse dimensions of that cavity, rather suspended in than confined by it. The rest of the space, amounting to about one third, is occupied by the roots of the nerves, liga-

Fig. 138.

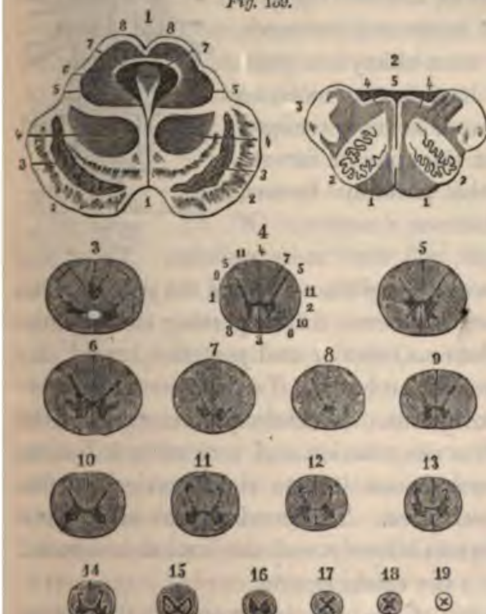
The spinal cord.

ments, the investitures of the cord, blood-vessels, and a liquid.

Fig. 138, A, A, shows the front view of the spinal cord, with the medulla oblongata; B, B, the posterior view; and C, C, the decussation of its strands, from which it appears that the organ is composed of two equilateral portions. They are united by an interior commissure, but separated in front by the anterior, and behind by the posterior fissure. Of these the posterior fissure is the deeper, the anterior being wider. Besides these regional divisions, the cord also presents longitudinal furrows, two for each side, dividing it into the anterior, the middle or lateral, and posterior columns or tracts, as shown in the figures.

With respect to the interior constitution of the cord, it has already been stated that it is composed exteriorly of white, and interiorly of gray material. The relative quantities of these, and the particular form and distribution of the gray substance, may, perhaps, be best understood from the sections given in *Fig.* 139, from one to nineteen, 1 showing a transverse section as high as the cerebral peduncles; 2, through the medulla oblongata; and the remaining figures, to 19, at lower and lower points.

Fig. 139.



Sections of the spinal cord.

In the first of these sections, 1 is the interpeduncular space; 2, 2, inferior tract; 3, 3, middle tract; 4, 4, locus niger; 5, 5, superior tract; 6, section of the aqueduct of Sylvius; 7, 7, section of the superior peduncles of the cerebellum; 8, 8, section of the two tubercula quadrigemina.

In the second section: 1, 1, the pyramidal bodies; 2, 2, olivary bodies; 3, 3, restiform; 4, 4, section of middle strands; 5, floor of fourth ventricle.

In the fourth of these sections: 1, the right half of the cord; 2, left half; 3, anterior median fissure; 4, posterior median fissure; 5, 5, pos-

terior furrows: 6, white or anterior commissure; 7, gray or posterior commissure; 8, anterior horn of right crescent; 9, posterior horn of ditto: it is prolonged to the posterior furrow; 10, antero-lateral columns; 11, 11, posterior columns: these are all of white tubular substance. The symmetrical reference numbers on one side are omitted for the sake of clearness.

Membranes of the spinal cord.

The spinal cord is surrounded by three membranes, continuous with those of the cranium: the dura mater, the arachnoid, and the pia mater. The latter embraces the cord so closely as to exert a compression upon it. This is shown on slightly wounding it, when the white substance protrudes through the orifice.

Fig. 140.

Spinal dura mater laid open.

Fig. 140: 1, spinal dura mater laid open and drawn aside; 2, 2, sheaths formed by this membrane round the roots and spinal ganglia; 3, spinal arachnoid; 4, 4, sheaths formed by the arachnoid around the roots of the nerves and dentated ligament; 5, 5, points of communication of the visceral layer of the arachnoid, with its parietal layer; 6, pia mater; 7, dentated ligament separating the anterior roots from the posterior roots of the spinal nerves, and serving as a communication between the dura mater and pia mater.

The spinal nerves.

From the spinal cord there arise thirty-one pairs of nerves, each nerve having two roots, an anterior or motor, and a posterior or sensory.

Roots of the spinal nerves.

The anterior roots issue from the anterior furrow, the posterior from the posterior furrow, where the gray substance emerges. Of the two the latter are the larger, and have more radicles. They also have, in the intervertebral foramen, a ganglion. Beyond the ganglion the two roots coalesce, and the resulting nerve trunk, passing through the intervertebral foramen, divides into an anterior and posterior branch, for the anterior and posterior portions of the body. To this general description there are, however, some exceptions. Thus the posterior root of the first cervical nerve is smaller than the anterior, and very often it has no ganglion. The spinal nerves are enumerated as eight cervical, twelve dorsal, five lumbar, and six sacral pairs. The cervical pass off to their distribution transversely, the dorsal obliquely, and the lumbar and sacral vertically. The latter constitute the cauda equina.

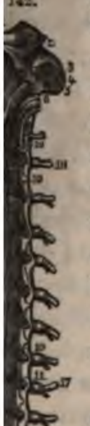
Fig. 141 illustrates the origin of the anterior roots of the spinal nerves. 1, pons varolii; 2, large and small root of the fifth pair; 3, sixth pair; 4, facial nerve; 5, auditory nerve; 6, intermedian nerve; 7, glosso-pharyngeal; 8, pneumogastric; 9, spinal accessory; 10, hypoglossal.

141.

anterior nerves.

From 11 to 11, the eight anterior roots of the cervical nerves; from 12 downward, the same roots of the dorsal nerves: those of the lumbar and sacral are not shown in the figure. As at 15, are shown the anterior branches of the spinal nerves; as at 16, their posterior branches; at 17, spinal ganglia formed on the posterior roots; 18, anterior roots cut; 19, anterior roots cut beyond the ganglion; 20, dentated ligament, separating anterior from posterior roots; 21, insertion of this ligament on dura mater by its dentated edge; 22, insertion of same ligament on the pia mater.

142.



posterior nerves.

Fig. 142 illustrates the origin of the posterior roots of the spinal nerves. 1, tubercula quadrigemina; 2, triangular band; 3, 3, superior peduncles of the cerebellum; 4, 4, middle peduncles of cerebellum; 5, 5, inferior peduncles of cerebellum; 6, anterior wall of fourth ventricle; 7, glosso-pharyngeal; 8, pneumogastric; 9, spinal accessory; from 10 to 10, posterior roots of eight cervical pairs: the dorsal, the lumbar, and the sacral below 11 are not shown in the figure. From 14 downward, a dotted line arising from the tearing away of the posterior roots; 15, 15, anterior roots of spinal nerves, the dentated ligament being visible through the removal of the posterior roots; 16, spinal ganglia, of which there are thirty pairs, the first pair of nerves not being furnished with them; 17, 17, anterior branches of spinal nerves; 18, 18, posterior branches; 19, 19, dentated ligament, placed between the posterior and anterior roots; 20, same ligament brought into view.

Fig. 143.

Origin of anterior and posterior roots.

Fig. 143 shows a portion of the spinal cord surrounded by its envelopes, and seen in profile, so as to display at once the origin of the anterior and posterior roots. 1, 1, posterior
f spinal nerves and their ganglia; 2, 2, anterior roots
same nerves anastomosing with the anterior portions
se ganglia; 3, 4, anterior and posterior roots cut;
tated ligament; 6, dura mater, preserved to show the
s which it forms around these ganglia and the branches
spinal nerves; 7, vertical section of the sheath of the
r and posterior roots, to show the little lamella which
es the one root from the other; 8, 8, interior face of
ra mater, which is drawn aside to show the smooth
which it possesses, owing to the parietal layer of the
oid which covers it.

The white or fibrous portion of the spinal cord is composed in part of the spinal nerve fibres and in part of commissural ones. At one time it was supposed that every one of the preceding continued uninterruptedly to the brain. On this point, however, the weight of evidence will lead us to infer that the vertical distance through which these fibres pass is not very great, and that they are soon brought in connection with the interior vesicular substance. If all the fibres passed uninterruptedly to the brain, we should expect that the cord would increase in thickness by a regular progression upward; but this, as is shown in *Fig.* 138, is not the case. Its enlargements correspond to the number of nerve roots given off from the localities in which they occur. Thus, where many nerve roots are required for the upper extremities, and again for the lower ones, we notice such corresponding enlargements. The experiments of Volkmann show that these dilatations are as much owing to an increase of the vesicular material as to an increased number of fibres. In the view presented in the preceding chapter respecting nerve-arcs and the functions of nerve-cells, we should be led to infer that every centrifugal and centripetal fibre of the cord is brought in connection with such a cell of the gray material, and that it does not extend very far from its point of exit or entrance.

Functions of the spinal cord.

FUNCTIONS OF THE SPINAL CORD.—The determination of the functions of the roots of the spinal nerves by Bell has already been referred to as one of the great discoveries of physiology, and as furnishing a solid foundation for an exact knowledge of the functions of the nervous system. The evidence of the truth of the doctrine that the anterior roots of these nerves are motor and the posterior sensory, is complete. Thus, if the anterior root of one of these nerves be divided, all those parts which are supplied by that nerve will exhibit loss of motion, though their sensation is unimpaired; if the posterior root be divided, the sensibility of the parts is lost, though the power of motion is unaffected. Similar evidence may also be obtained by irritating the ends of the divided roots, muscular motion or pain, as the case may be, being correspondingly observed.

Bell's discovery.

Longitudinal transmission of influences.

The spinal cord transmits impressions from the periphery to the brain, and conversely enables the brain to bring into action the motor nerves. Division of it at once causes an interruption of voluntary motion and sensation in those parts supplied by nerves below the place of the operation, the functions of the parts above remaining unimpaired. But, though the influence of the brain in exciting voluntary motion, and its capability of receiving sensations, is thus cut off, the severed portion of the cord still possesses an automatic power.

This transmission of influences upward or downward is doubtless, to

considerable degree, accomplished through the vesicular substance, the uality of which, in this respect, has been explained in the preceding hapter. But, besides this, the exterior fibrous structures possess a like unction, correspondingly as they are connected with the motor or senory roots of the nerves, the anterior columns being motor, and the poserior apparently sensory.

Transverse transmission of influences.

The spinal cord not only permits the passage of influences in its longiudinal, but also in its transverse direction. This is what night be anticipated from the structure and functions of the ells of its gray interior. If the cord be cut half through in given place, and again be cut half through on the opposite side, at a ittle distance above or below, impressions may be conducted through he intermediate portion, the vesicular material being then their only hannel.

Brown-Sequard on the conduction of the cord.

In a memoir on the distribution of the fibres of the sensitive roots, and n the transmission of impressions in the spinal cord, Dr. Brown-Sequard, referring to the two theories entertained at resent—1st. That sensitive impressions reaching the cord ass in totality to the brain along the posterior columns; 2d. That such mpressions so arriving pass directly to the central gray substance, which ransmits them upward—offers reasons for supposing that both these heories, and especially the first, are contradicted by facts.

It is his opinion that sensitive impressions reaching the cord pass in lifferent directions, some ascending, others descending, but both going in art by the posterior columns, and in part by the posterior gray horns, nd perhaps by the lateral columns, to penetrate, after a short distance, he gray central substance by which, or in which, they are transmitted o the brain.

He also shows that sensitive impressions of one lateral half of the ody are transmitted principally in a crossed manner, that is to say, that hey follow more particularly the opposite half of the cord to reach the rain; that the decussation of the conducting elements for sensitive imressions is not made, as is commonly said, at the anterior extremity of he pons; that the gray substance does not possess the property of ransmitting sensitive impressions in every direction, as some have supposed; that most, if not all the conducting elements for sensitive imressions decussate in the spinal cord, the decussation occurring in part lmost immediately on their entry into the cord, but that a few make heir decussation at a certain distance above the point of entry, the majority, however, descending in the cord, and making their decussation elow the point of entry; that if there are conducting elements for sensitive impressions which ascend throughout the entire length of the cord o make their decussation in the brain, their number must be very small;

and that alterations capable of producing a paralysis of sensibility, and situated upon any point of a lateral half of the cerebro-spinal axis, always produce a paralysis of sensibility on the opposite half of the body, and that there is no difference between the brain and the spinal marrow in this respect.

Analogy with ventral cord of articulata.

Thus constructed, the spinal cord, as we shall presently show from Dr. Carpenter, evidently agrees with the gangliated ventral cord of the articulata, each portion of it from which a pair of nerves is given off representing each ganglion of that ventral cord, the difference in the two structures being, that in the spinal column the ganglia are commissured, so as to form, in appearance, one continuous mass, and agreeably to this view of its construction are the circumstances under which its enlargements occur. In those animal forms in which the entire trunk is concerned in locomotion, as in snakes and eels, the cord is nearly cylindrical; but as soon as special members for locomotion are developed, a corresponding increase of diameter is observed. Thus, in birds, the ganglionic enlargement corresponds with the region from which the nerves for the wings are given off; but in that tribe, as in the ostrich, the mode of locomotion of which is by the legs rather than by the wings, a corresponding posterior enlargement occurs. The same observations may even be more distinctly made during metamorphoses; thus, in frogs, while they are in the tadpole state the spinal cord is cylindrical, but bulging ensues in it anteriorly and posteriorly as soon as the anterior and posterior members are developed.

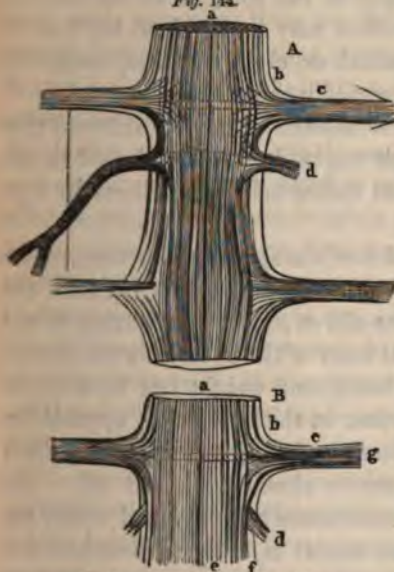
Reflex action of the cord.

The translation of impressions which have been brought along the centripetal fibres into motions, the exciting influence of which is conveyed along the centrifugal fibres, includes what is understood as the reflex action of the spinal cord as developed by Dr. Hall. Its essential condition is its independence of the agency of the brain, and therefore unconscious nature. As general examples may be mentioned the movements which occur in swallowing; for after the food has been carried by voluntary action into the fauces, its passage onward to the stomach is perfectly involuntary. In like manner, the introduction of air into the lungs in ordinary respiration is involuntary; for though it may be, to a certain extent, under the control of the will, yet that extent is limited, a necessity for the motion presently arising, which soon becomes uncontrollable. The action of the valvular arrangements at the cardiac and pyloric orifices of the stomach, and the constant contraction of the sphincter ani, are farther illustrations. To these may be added those impulsive movements which we instinctively make on the approach of danger or in the act of falling, and perhaps, too, automatic walking, as we go from place to place in a state of mental abstraction, paying no attention to the course we take.

The cord is to be regarded as a longitudinal series of simple automatic nerve arcs, or, as we have termed it, a multiple automatic arc. Each segment of it has therefore an independent action of its own, but can conspire with its neighbors or be influenced by the brain, by means of its commissural fibres, an arrangement of which numberless interesting instances might be furnished. The one represented in *Fig.* 144, which is from the cord of spirostreptus, may, however, suffice: A, under surface of a portion; B, upper surface; *a*, inferior longitudinal fibres; *e*, superior longitudinal fibres; *f*, fibres of re-enforcement, seen also at *b* and *c*; *g*, commissural fibres, seen also at *d*.

Automatic action of the cord.

Fig. 144.



Portion of cord of spirostreptus.

The power which the cord displays in this simple action is most strikingly seen when it is cut off from its cranial connections. The decapitated frog props himself up stiffly on his legs, and, if his cutaneous surface be irritated, exhibits antagonizing motions; such motions are all of the reflex character, and are commonly much more strikingly seen in cold than in warm-blooded animals; but even in man precisely the same results are witnessed during periods of the suspension of the activity of the brain, as, when the palm of the hand of a sleeping child is touched with the finger, the finger is at once grasped.

As above stated, this reflex function of the cord is therefore independent of the brain, though the brain can control it, and this the more perfectly the higher the organization of the animal. Breathing can go on, whether we pay attention to it or not, but we can arrest it if we choose for a time; and since in man this introduction of air is incidentally used for very refined purposes, by voluntary exertion we moderate or regulate it, as in the production of musical sounds in singing or of articulate sounds in speech.

Reflex action independent of the brain.

In a general way, there is not much difficulty in distinguishing between simple actions of the cord and those in which the brain is participating. In the former, no weariness or fatigue is ever experienced; in the latter it is; and perhaps, even in these last, involving voluntary muscular action, though the control is to be attributed to the brain, the source of the force is in the cord.

Distinction between spinal and cerebral action.

These normal phenomena which the cord displays become greatly ex-

Increase of spinal action.

aggerated in certain conditions of disease, as, for example, in tetanus, in which the slightest peripheral irritation may be followed by violent convulsive movement, or the same occurs by the agency of powerful poisonous substances, as strychnine. In these cases the action may be either limited simply to the cord, as in the tetanus brought on by opium in frogs, or the brain may be involved in it, as in cases of hydrophobia, in which the sound or sight of water, operating through the cerebrum, will produce spasmodic convulsions.

From the facts presented by the lower animals, it may be inferred that the spinal cord does not act as a single organ, but rather should be regarded as a collection of ganglia, special duties being discharged by special parts of it.

Connection of the cord and brain.

With respect to the commissural action of the spinal cord, reference has already been made to the structural connection between the cord and the nervous regions above it, and in referring to the old anatomical doctrine that each of the spinal nerves is connected by continuous fibres with the brain, due weight has been given to the fact that the cord does not increase in thickness as it approaches the brain, but that its bulgings correspond to the regions from which it is necessary that an unusual supply of nerves should be given off. The force of this argument is, however, considerably diminished when we recollect that the nerve-tubes are by no means of uniform diameter, but are doubly conical in shape. Even, therefore, with a diminished diameter of the spinal cord, there might be an upward continuation of spinal fibres, the diameter of which is becoming less and less; and this seems to be rendered more likely from the analogy of the structure of the ventral cord of the articulata, in which fibres are sent to the cephalic ganglia for the purpose of establishing a communication between them and the roots of the nerves. But, however that may be, there can be no question of the influence of the brain over spinal action, and this, of course, implies structural connection of some kind—an intercommunication—which, if it does not take place solely through the white columns, must take place through the gray material. It is, however, important to observe that the gray material has no direct communication with that of the cerebrum, but, passing through the optic thalamus, ends in the corpus striatum, extending therefore in one continued mass through the cord, and terminating in that ganglionic organ. By one or both of these channels, white or gray, the impressions which are made upon the spinal sensitive nerves are presented to the brain, and in a similar manner the influences which produce voluntary motions are transmitted down. A

Effect of lesions of the cord.

section of any part of the spinal cord at once incapacitates the will from acting upon the parts beyond, the motions of which become therefore purely automatic, though the parts above still

lisplay their customary phenomena. These effects are sometimes instructively witnessed in man when lesions of the cord have occurred through disease.

Motor and sensory tracts of the cord.

If the view that has been presented respecting the continuation of fibres from the cord to the brain be correct, these fibres discharge a commissural duty. This would lead us to suppose that there is a correspondence between the functions of the columns of the cord and those of the roots of the spinal nerves, the anterior columns being motiferous, or in unison with the motor root of the nerves, the posterior being sensiferous, or in unison with the sensory root of the nerves. Agreeably to this, if the anterior columns be irritated, motions are excited in all those parts which are supplied with nerves beyond the irritated point; and if the posterior columns be irritated, in like manner pain is experienced. In this instance, however, a certain amount of motion is occasionally observed, but this has commonly been explained by referring it to reflexion within the cord. It has also been observed, as strengthening these views, that if the posterior columns be irritated after complete section of the cord, the result will depend on which of the cut portions be disturbed; if it be the lower, there will be no effect. An examination, under the same circumstances, of the anterior columns, demonstrates that, if the upper section be irritated, there is no effect produced; if the lower, there are convulsive movements of the parts supplied with nerves beyond.

From these results we should infer that the physiological functions of the anterior and posterior roots of the spinal nerves are participated in by the anterior and posterior columns of the cord, and might therefore expect that those functions would be continued in the higher distribution of the columns above the medulla oblongata.

General functions of the cord.

From the point of view under which we have thus presented it, the action of the spinal cord is therefore simple, or it is disturbed by the agency of the brain; in the first case it offers itself purely as an automatic instrument; in the latter, its commissural connections with the brain make a compound apparatus. The former state is closely represented in the construction of the amphioxus, the nervous system of which has no rudiment of a cerebrum or cerebellum; in this animal, therefore, since also the sensory ganglia are merely in a rudimentary state, the mode of life must be purely mechanical, just as it is with an artificial automaton, of which, when a given spring is touched, a given motion is made. Even among the highest vertebrated animals, man himself at the periodic times of quiescence of the cerebrum, as in sleep, when the cerebral influence over other portions is, to a certain extent, suspended, an approach to a similar condition occurs; but in periods of activity of the cerebrum, it can hold the spinal cord in check,

controlling, and in some cases arresting its action, and this is done through influences propagated along the tubular structures of the posterior and anterior columns, which therefore are to be regarded, in this respect, as commissures to the brain.

OF THE MEDULLA OBLONGATA.

The medulla oblongata is a conical body, lying between the spinal cord and the brain. It is generally understood to be bounded at its upper portion by the pons varolii, but this is not a true limit, since its structure extends through the pons varolii to the crura of the brain. There is the same indefiniteness of limit as respects its lower boundary, which is generally said to be marked by some decussating fibres which appear on its front. Like the spinal cord, it has an anterior and posterior fissure, which divide it into two symmetrical lateral halves; the former is a continuation of the anterior spinal fissure, the latter of the posterior, and ends in the calamus scriptorius above. The lateral halves thus produced are marked by three grooves, producing four eminences, which pass under the following names: 1st. The anterior pyramids; 2d. The olivary bodies; 3d. The restiform bodies; 4th. The posterior pyramids. The anterior fissure is crossed about an inch below the pons varolii by decussating fibres, and hence injuries on one side of the brain produce nervous effects on the opposite side of the body.

Limits of the medulla oblongata.

Its subdivisions.

First. The anterior pyramids consist of white fibres originating near the decussating fasciculi. They have a compound structure, for each contains fibres arising from the inner side of the opposite anterior column of the cord, and also fibres from its own side: they pass through the pons varolii into the crus cerebri. From these pyramids curved fibres pass round the olivary body, and are lost in the restiform. They are called arciform fibres.

The anterior pyramids.

Second. The corpora olivaria receive their name from their olive shape. They are separated by a groove from the preceding in front, and by another groove from the restiform bodies behind. Externally, they are formed of white tubular tissue, which incloses a vesicular mass, the olivary ganglion, which connects with the vesicular structure of the pons above, and that of the cord below. The fibres of these ganglia are called the olivary tracts. They are continuous with the central part of the medulla oblongata, passing behind the pyramids, extending upward along the posterior part of the crura cerebri to the optic thalami and tubercula quadrigemina. The olivary bodies exist only in man and the monkey tribe.

The olivary bodies.

Third. The restiform bodies are separated from the olivary by a *groove.* They are continuous with the posterior and antero-lateral col-

umns of the cord. Ascending, they enter the cerebellum, and are continuous with the inner part of its crus. They therefore are a tract of communication from the spinal cord to the cerebellum. They each inclose a gray nucleus, which is the ganglion of the pneumogastric nerves, and of some of the roots of the glosso-pharyngeal.

The restiform bodies.

Fourth. The posterior pyramids are doubtfully marked off from the restiform bodies in front, and are separated from each other by the posterior fissure. Superiorly, their fibres are continuous with the sensory tract of the crura cerebri: their gray nuclei are the ganglia of the auditory nerves.

The posterior pyramids.

Fig. 145.

Front of medulla oblongata.

The structure of the medulla oblongata is exemplified in the annexed figures.

Fig. 145: 1, chiasm of the optic nerves; 2, crus cerebri; 3, tuber cinereum; 4, corpora albicantia; 5, locus perforatus; 6, pons varolii; 7, section of the middle peduncle of cerebellum; 8, transverse fissure, separating the medulla from the pons; 9, first enlargement of the cord, or medulla oblongata; 10, anterior pyramid; 11, olivary body; 12, anterior portion of restiform body; 13, neck of the medulla oblongata; from 16 downward is the anterior median fissure; from 17 downward, the anterior lateral furrow.

Fig. 146.

Posterior view of medulla oblongata.

Fig. 146: 1, section of optic tract; 2, tubercula quadrigemina; 3, triangular band; 4, section of crus cerebelli; 5, medulla oblongata; 6, anterior floor of the fourth ventricle; 7, median fissure of the fourth ventricle, aiding to form the calamus scriptorius; 8, mammillary swelling near the nib of the pen; 9, posterior portion of the restiform body; from 12 downward, posterior median fissure; from 13 downward, lateral furrow; from 14 downward, posterior furrow.

Fig. 147.

Interior construction of the medulla and pons.

Fig. 147: 6, anterior column of the cord, divided superiorly into two portions, of which the most internal one contributes to the formation of the corresponding pyramid; 7, middle or lateral column, divided superiorly into three or four portions, decussating with as many portions of the column of the opposite side, the decussation taking place both laterally and antero-posteriorly: it is the origin of the internal two thirds of the pyramid; 8, 8, pyramids; 9, white fibres of the pyramid, traversing the pons, and continuing to the crus

Fig. 148.

Posterior view of medulla oblongata.

cerebri; 10, superficial section of the transverse fibres of the pons; 11, deeper section of the transverse fibres of the pons; 12, olivary body; 13, right olivary body, brought into view by removal of the corresponding pyramid.

Fig. 148 is a posterior view of the medulla oblongata: *p*, *p*, posterior pyramids, separated by a posterior fissure; *r*, *r*, restiform bodies, composed of, *c*, *c*, posterior columns, and *d*, *d*, part of antero-lateral columns of the cord; *a*, *a*, olivary columns, as seen on the floor of the fourth ventricle, separated by *s*, the median fissure, and crossed by some fibres of origin of, *n*, *n*, the seventh pair of nerves.

FUNCTIONS OF THE MEDULLA OBLONGATA.

Functions of the medulla: it is a tract of communication.

Viewed as a superposed continuation of the spinal cord, the medulla oblongata is the tract of communication between that organ and the brain: the anterior pyramids and olivary tracts convey motor influences, and the restiform tracts and posterior pyramids sensations. By experiments similar to those which have been performed upon the cord, these conclusions have been maintained.

But, besides this function of conduction, the medulla oblongata discharges a most important duty as a nervous centre; on it depend respiration and deglutition. The brain may be wholly removed above, and the spinal cord below, as far as the origin of the phrenic nerve, without death necessarily ensuing, but on wounding the medulla oblongata, the muscular movements necessary for the introduction of air are necessarily stopped.

Its relations to respiration.

Moreover, the medulla oblongata exhibits the property of reflex action. So far as the function of respiration is concerned, its chief centripetal nerve is the pneumogastric, but the power which it possesses is participated in by many others, perhaps by reason of the venous condition into which the blood is brought from want of proper aeration. The violent respiratory movements by the sudden application of cold to the skin, the shower-bath, or dashing cold water on the face, are converted by it into respiratory muscular motions. From it also arise the movements required in the act of deglutition.

Under this view of the functions of the medulla oblongata, it is to be regarded as an exclusively automatic instrument, which can continue its

operation after the excision of the brain. As with the spinal cord, so with it: its simple action may continue though its commissural action has ceased, and this either through conditions of disease or by the administration of drugs. In lesions of the brain respiration may still continue, as it may also when sensation and voluntary motion have been arrested by the breathing of chloroform.

OF THE PONS VAROLII.

Structure of the pons varolii.

The pons varolii consists of a loop of fibres passing from one crus cerebelli to the other, around the tracts of communication between the cord and the brain. As shown in *Fig.* 145, they do not form a continuous superficial commissure, but, at a certain distance below, interlace with the fibres of the pyramids; moreover, among their deeper fibres gray vesicular matter occurs. That they constitute mainly a commissure for the cerebellum is apparent from the circumstance that, in those animals which have the median cerebellar lobe only, there is no pons, and in other cases its relative magnitude is in proportion to the size of the cerebellar hemispheres.

FUNCTIONS OF THE PONS VAROLII.

Functions of the pons.

The functions of the pons varolii are therefore twofold: it acts as a conductor, and also as a nerve centre. In the first respect, it is the channel from the spinal column to the cerebrum and cerebellum, and also between the cerebellar halves, and experiments upon it, in giving rise to sensations and motions, are in conformity with what we should anticipate from the structure and functions of the spinal cord.

In the second respect, as a nervous centre, it has been stated that, when the cerebrum and cerebellum are removed, but the pons left untouched, an animal gives tokens of sensation when pinched or irritated, and likewise executes motions which have an object; these, however, were no longer observed after the removal of the pons.

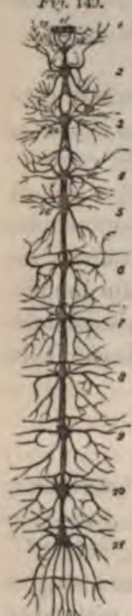
Dr. Carpenter's views of the analogy between the spinal cord of vertebrates and the ventral cord of articulates.

We have had repeated occasion already to mention that the surest guide which can be followed in interpretations of the functions of the nervous system is comparative physiology. Our views of the action of the spinal cord, medulla oblongata, and even portions above, hereafter to be described, will be rendered clear by a knowledge of the structure and functions of the ventral cord of the articulata, the analogy of which to the parts we have had under consideration was first correctly pointed out by Dr. Carpenter. I therefore transcribe from his General and Comparative Physiology the following paragraphs, which present his views with perspicuity.

"The plan on which the nervous system is distributed in the sub-

kingdom articulata exhibits a remarkable uniformity throughout the whole series, while its character gradually becomes more elevated as we trace it from the lowest to the highest divisions of the group. It usually consists of a double nervous cord studded with ganglia at intervals, and the more alike the different segments, the more equal are these ganglia. The two filaments of the nervous cord are sometimes at a considerable distance from one another, and the ganglia are distinct, but more frequently they are in close apposition, and their ganglia appear single and common to both. That which may seem as the typical conformation of the nervous system of this group is seen in the ganglionic cord of *scolopendra*, or in that of the larvæ of most insects, such as that of the *sphinx ligustri*, *Fig.* 149. Here we see the nervous cord nearly uniform throughout, its two halves being separated, however, in the anterior portion of the body. The ganglia are disposed at tolerably regular intervals, are similar to each other in size (with the exception of the last, which is formed by the coalescence of two), and every one supplies its own segment, and has little connection with any other. The two filaments of the cord diverge behind the head to inclose the œsophagus, above which we find a pair of ganglia that receive the nerves of the eyes and antennæ. We shall find that in the higher classes the inequality in the formation and office of the different segments, and the increased powers of special sensation, involve a considerable change in the nervous system, which is concentrated about the head and thorax. In the simplest vermiform tribes, on the other hand, we lose all trace of separate ganglia, the nervous cord passing without evident enlargement from one extremity to the other. Whatever may be the degree of multiplication of the ganglia of the trunk, they seem but repetitions of one another, the functions of each segment being the same with those of the rest. The *cephalic* ganglia, however, are always larger and more important. They are connected with the organs of special sense, and they evidently possess a power of directing and controlling the movements of the entire body, while the power of each ganglion of the trunk is confined to its own segment.

Fig. 149.



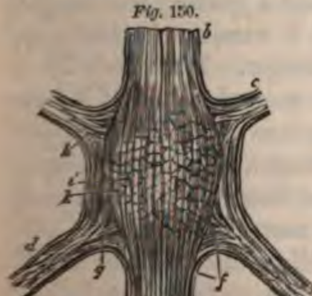
Nervous system of larva of sphinx ligustri.

"The longitudinal ganglionic cord of the articulata occupies a position which seems at first sight altogether different from that of the nervous system of vertebrated animals, being found in the neighborhood of the *ventral* or inferior surface of their bodies, instead of lying just beneath their *dorsal* or upper surface. From the history of their development, however, and from some other considerations, it has been suggested that the *whole* body of these animals may be considered as in an inverted po-

sition, the part in which the segmentation is first distinguished in insects being the equivalent of the dorsal region in vertebrata, and that over which the germinal membrane is last to close in, being homologous with the ventral region. This view applies also to the position of the dorsal vessel, which would then be on the ventral side of the axis, as in vertebrata. Regarded under this aspect, the longitudinal nervous tract of articulata corresponds with the spinal cord of vertebrated animals in position, as we shall find it does in function.

"When the structure of the chain of ganglia is more particularly inquired into, it is found to consist of two distinct tracts, one of which is composed of nerve fibres only, and passes backward from the cephalic ganglia over the surface of all the ganglia of the trunk, giving off branches to the nerves that proceed from them, while the other includes the ganglia themselves. Hence, as in the mollusca, every part of the body has two sets of nervous connections, one with the cephalic ganglia, and the other with the ganglion of its own segment. Impressions made upon the afferent fibres which proceed from any part of the body to the cephalic ganglia become sensations when conveyed to the latter, while in respondence to these, the consensual impulses, operating through the cephalic ganglia, harmonize and direct the general movements of the body by means of the efferent nerves proceeding from them. For the purely reflex operations, on the other hand, the ganglia of the ventral cord are sufficient, each one ministering to the actions of its own segment, and to a certain extent, also, to those of other segments. It has been ascertained by the careful dissections of Mr. Newport, to whom we owe all our most accurate knowledge of the nervous system in articulated animals, that of the fibres constituting the roots by which the nerves are implanted in the ganglia, some pass into the vesicular matter of the ganglion, and, after coming into relation with its vesicular substance, pass out again on the same side (*Fig.* 150, *f*, *k*), while a second set, after traversing the vesicular matter, pass out by the trunks proceeding from the opposite side of the same ganglion, and a third set run along the portion of the cord which connects the ganglia of different segments, and enter the nervous trunks that issue from them at a distance of one or more ganglia above or below.

Fig. 150.



Ganglion of polydesmus maculatus.

"*Fig.* 150, from ganglionic tract of polydesmus maculatus. *b*, interganglionic cord; *c*, anterior nerves; *d*, posterior; *f*, *k*, fibres of reflex action; *g*, *h*, commissural fibres; *i*, longitudinal fibres, softened and enlarged as they pass through the ganglionic matter.

"Thus it appears that an impression con-

veyed by an afferent fibre to any ganglion may excite motion in the muscles of the same side of its own segment, or in those of the opposite side, or in those of segments at a greater or less distance, according to the point at which the efferent fibres leave the cord; and as the function of these ganglia is altogether related to the locomotive actions of the segments, we may regard them as so many repetitions of the pedal ganglia of the mollusca, their multiplication being in precise accordance with that of the instruments which they supply.

"The general conformation of articulated animals, and the arrangement of the parts of their nervous systems, render them peculiarly favorable subjects for the study of the reflex actions, some of the principal phenomena of which will now be described. The mantis religiosa customarily places itself in a curious position, especially when threatened or attacked, resting on its two posterior pairs of legs, and elevating its thorax with the anterior pair, which are armed with powerful claws; now if the anterior segment of the thorax, with its attached members, be removed, the posterior part of the body will still remain balanced upon the four legs which belong to it, resisting any attempts to overthrow it, recovering its position when disturbed, and performing the same agitated movements of the wings and elytra as when the unmutilated insect is irritated; on the other hand, the detached portion of the thorax, which contains a ganglion, will, when separated from the head, set in motion its long arms, and impress their hooks on the fingers which hold it. If the head of a centipede be cut off while it is in motion, the body will continue to move onward by the action of the legs, and the same will take place in the separate parts if the body be divided into several distinct portions. After these actions have come to an end, they may be excited again by irritating any part of the nervous centres, or the cut extremity of the nervous cord. The body is moved forward by the regular and successive action of the legs, as in the natural state, but its movements are always forward, never backward, and are only directed to one side when the forward movement is checked by an interposed obstacle. Hence, though they might seem to indicate consciousness and a guiding will, they do not so in reality, for they are carried on, as it were, mechanically, and show no direction of object, no avoidance of danger. If the body be opposed in its progress by an obstacle of not more than half of its own height, it mounts over it, and moves directly onward as in its natural state; but if the obstacle be equal to its own height, its progress is arrested, and the cut extremity of the body remains forced up against the opposing substance, the legs still continuing to move. If, again, the nervous cord of a centipede be divided in the middle of the trunk, so that the hinder legs are cut off from connection with the cephalic ganglia, they *will continue* to move, but not in harmony with those of the fore part of

the body, being completely paralyzed, so far as the animal's controlling power is concerned, though still capable of performing reflex movements by the influence of their own ganglia, which may thus continue to propel the body in opposition to the determinations of the animal itself. The case is still more remarkable when the nervous cord is not merely divided, but a portion of it is entirely removed from the middle of the trunk; for the anterior legs still remain obedient to the animal's control, the legs of the segments from which the nervous cord has been removed are altogether motionless, while those of the posterior segments continue to act through the reflex powers of their own ganglia, in a manner which shows that the animal has no power of checking or directing them.

"The stimulus to the reflex movements of the legs in the foregoing cases appears to be given by the contact of the extremities with the solid surface on which they rest. In other instances the appropriate impression can only be made by the contact of liquid. Thus a *dytiscus* (a kind of water-beetle), having had its cephalic ganglia removed, remained motionless as long as it rested upon a dry surface, but when cast into water it executed the usual swimming motions with great energy and rapidity, striking all its comrades to one side by its violence, and persisting in these for more than half an hour. Other movements again may be excited through the respiratory surface. Thus, if the head of a *centipede* be cut off, and, while it remains at rest, some irritating vapor (such as that of ammonia or muriatic acid) be caused to enter the air-tubes on one side of the trunk, the body will be immediately bent in the opposite direction, so as to withdraw itself as much as possible from the influence of the vapor; if the same irritation be then applied to the other side, the reverse movement will take place, and the body may be caused to bend in two or three different curves by bringing the irritating vapor into the neighborhood of different parts of either side. This movement is evidently a reflex one, and serves to withdraw the entrances of the air-tubes from the source of irritation, in the same manner as the acts of coughing and sneezing in the higher animals cause the expulsion from the air-passages of solid, liquid, or gaseous irritating matters which may have found their way into them.

"From these and similar facts, it appears that the ordinary movements of the legs and wings of articulated animals are of a reflex nature, and may be effected solely through the ganglia with which these organs are severally connected; while, in the perfect being, they are harmonized, controlled, and directed by impulses which act through the cephalic ganglia, and the nerves proceeding from them. There is strong reason to believe that the operations to which these ganglia are subservient are almost entirely of a consensual nature, being immediately prompted by sensations, chiefly those of sight, and seldom or never by any processes

of a truly rational character. When we attentively consider the habits of these animals, we find that their actions, though evidently directed to the attainment of certain ends, are very far from being of the same spontaneous nature, or from possessing the same designed adaptation of means to ends as those performed by ourselves, or by the more intelligent vertebrata under like circumstances. We judge of this by their unvarying character, the different individuals of the same species executing precisely the same movements when the circumstances are the same, and by the very elaborate nature of the mental emotions which would be required in many instances to arrive at the same results by an effort of reason. Of such we can not have a more remarkable example than is to be found in the operations of bees, wasps, and other social insects, which construct habitations for themselves upon a plan which the most enlightened human intelligence, working according to the most refined geometrical principles, could not surpass, but which yet do so without education communicated by their parents or progressive attempts of their own, and with no trace of hesitation, confusion, or interruption, the different individuals of the community all laboring effectively to one purpose, because their automatic impulses (producing what are usually termed instinctive actions) are all of the same nature.

"Not only are the locomotive ganglia multiplied in accordance with the repetition of segments and members, but the respiratory ganglia are multiplied in like manner in accordance with a repetition of respiratory organs. The respiratory division of the nervous system consists of a chain of minute ganglia lying upon the larger cord, and sending off its delicate nerves between those that proceed from the ganglia of the latter, as seen in *Fig.* 151. These respiratory ganglia and their nerves are best seen in the thoracic portion of the cord, where the cords of communication between the pedal ganglia diverge or separate from one another; and this is particularly the case in the pupa state, when the whole cord is being shortened and their divergence is increased. The thoracic portion of the cord is shown in *Fig.* 152, B, which represents the second, third, and fourth double ganglia of the ventral cord, the cords of connection between them here widely diverging laterally, and the small respiratory ganglia which are connected with each other by delicate filaments that pass over the ganglia of the ventral cord, and which send off lateral branches that are distributed to the air-tubes and other parts of the respiratory apparatus, and communicate with those of the other system."

Fig. 151.

A
Ganglion of centipede.

Illustrations of the nervous system of the articulata. *Fig.* 151, A, single ganglion of *centipede*, much enlarged, showing the distinctness of the purely fibrous tract, *b*, from the ganglionic column, *a*. *Fig.* 152, B, portion of the

Fig. 152.

B
Thoracic portion of cord of sphinx ligustri.

Fig. 153.

Combination of respiratory and locomotive ganglia.

double cord from the thorax of the pupa of sphinx ligustri, showing the respiratory ganglia and nerves between the ganglia 2, 3, 4, and the separated cords of the locomotive system. *Fig.* 153, C, view of the two systems combined, showing their arrangement in the larva: *a*, ganglion of the ventral cord; *b*, fibrous tract passing over it; *c*, *c*, respiratory system of nerves, distinct from both.

Having thus presented the views of Dr. Carpenter respecting the analogy between the ventral cord of the articulata and the spinal cord of the vertebrata, I should next continue the explanations which this physiologist has offered of the connections and relations of the sensory ganglia; but this can not be conveniently done until we have passed through the description of the organs at the base of the brain.

CHAPTER XVI.

OF THE BRAIN.

The Brain: its Structure.—Its Motor and Sensory Parts, Hemispheres, and Commissures.—The Sensorium.—Variations of the Hemispheres in Size and Weight.—Instrumental Nature of Cerebrum.—The Cerebellum: its Structure and Functions.—Co-ordinates muscular Motions.—Connection with Amativeness.—Phrenology.—Conditions of Action of Brain.

Symmetrical Doubleness of the Brain.—Function of each Half, and of both conjointly.—Independence and Insubordination of each Hemisphere.—Double Thought.—Alternate Thought.—Sentiment of Pre-existence.—Loss of Perception of Time.

General view of structure of brain.

THE cerebrum and cerebellum, being organs additional to the spinal cord, and developed, as has been shown in the last chapter, upon it, the cord being able to discharge its own functions independently of them, we shall find it at once the most natural and most commodious method to consider their structures as arising out of its structure, and their functions as having relation to its functions.

A general idea of the structure of the brain as an appendage to the

spinal cord may be gathered by considering that a bifurcation of the fibres takes place in the medulla oblongata, and upon one of the resulting bundles, the crus cerebri, the cerebrum is formed, on the other the cerebellum. The crus cerebri is composed of three strands: an inferior, the fibres of which have come from the anterior pyramids, and in part from the olivary bodies. This strand ends in the corpus striatum, its fibres not, however, blending abruptly with the vesicular matter, but passing into it in bundles. It is essentially motor. A superior, which is derived from the posterior pyramids, and terminates in the thalamus. It is essentially sensory. Between these, constituting the third portion—strand it can scarcely with propriety be called—is a layer of dark vesicular material, the locus niger. It is to be understood that the motor strands of the opposite sides decussate in the medulla oblongata; the sensory strands decussate in the mesocephalon.

Formation of the cerebellum.

The other bundle, arising in the original bifurcation, assumes the designation of crus cerebelli. On it the cerebellum is developed. It consists essentially of fibres from the restiform bodies, re-enforced by others which have come from the anterior pyramids under the name of arciform fibres. These together make their way to the interior ganglion of the cerebellum, the corpus dentatum, and there they end. But the crus cerebelli contains likewise two other great strands: an inferior, which constitutes the commissure of the two cerebellar hemispheres, and which, running round the entire prolongations of the spinal cord, forms the pons varolii; a superior, the processus cerebelli ad testes, which unites the cerebellum and cerebrum.

Of the portions of the spinal cord on which the cerebrum is to be developed, those which are sensory end in the optic thalamus, those which are motor in the corpus striatum. The thalamus and striatum of each side may be regarded as one compound ganglion, since, like the columns of the cord, they are united by a gray and a white commissure. Of the portions on which the cerebellum is to be developed, the termination is in the central ganglion of the cerebellum, the corpus dentatum.

Olivary body.

At the place of bifurcation of the constituent strands of the crus cerebri and crus cerebelli from each other in the medulla oblongata, there is intercalated or included a ganglion, which, with its apparatus, constitutes the olivary body, the fibres of which make their way upward between the two preceding bundles, and, having bifurcated, one branch goes to the quadrigemina and the other to the optic thalamus, the latter constituting, as has been said, a part of the crus cerebri. The seat of power of the medulla oblongata is in this ganglion.

Such being the anatomical construction of the crus cerebri, it may be physiologically regarded as a compound strand, the anterior portion of

which is motor, the posterior sensory; and between these a dark vesicular deposit, the locus niger, which is continuous between the vesicular matter in the spinal cord and that of the thalamus and corpus striatum. From the lowest extremity of the cord to these great ganglia there is, therefore, an unbroken vesicular channel. In its progress onward to the corpus striatum, the anterior strand yields roots of the spinal accessory, hypoglossal, facial, abducens, the small root of the fifth, the trochlearis, and the oculo-motor nerves. If there were no other proof of the motor character of this strand, the motor property of all these nerves would be sufficient to determine it. In like manner, the posterior strand yields the pneumogastric, the glosso-pharyngeal, and the sensory root of the fifth, from the sensory functions of which its sensory character is established.

Nerves of the motor and sensory strands respectively.

The layer of vesicular matter which is found upon the cerebral convolutions, and which is doubtless the seat of the higher intellectual qualities, has therefore no communication with the vesicular matter of the spinal axis, by contact or continuation, but only through the intervention of fibres which radiate upon it in all directions from the thalamus and striatum, or rather through some which radiate from the great sensory centre, the thalamus, to the periphery of the cerebrum, and others which converge from that periphery to the great motor centre, the striatum. If the diameter of these fibres be assumed to be $\frac{1}{10000}$ of an inch, there must be many millions of them in the aggregate. The vesicular matter of the hemisphere is arranged on the superficies instead of centrally, on account of the necessities of their structure and condition of activity, for thereby a great surface is obtained, which is further increased by the artifice of convolutions, a vesicular surface which, counting in that of the cerebellum, has been estimated at 670 square inches, and blood can be copiously supplied and freely removed.

Relation of the vesicular matter of the hemispheres.

But the thalamus and striatum are only two of a chain of ganglia beneath the cerebral hemispheres. Anteriorly we find the olfactive ganglia, or bulbs of the olfactory nerves, which are seated upon peduncles, though their character is manifest from the gray matter they contain. Behind these are the tubercula quadrigemina, to which the optic nerves run, and which are therefore their ganglionic centres. What answers to the auditory ganglion is lodged at a distance back, at the fourth ventricle, and the gustatory ganglion is in the medulla oblongata. These are the ganglia of special sense, and to be regarded as subordinate to the thalamus, which is their common register.

Ganglia at the base of the brain.

All these parts are commissured with one another, and with their fellows of the opposite half of the brain. Indeed, so likewise are all its

Commissures of the brain.

parts, the different cerebral lobes, the opposite hemispheres, adjacent and distant convolutions, the cerebrum with the cerebellum. Hence arises a structure of extreme complexity. Among the commissural apparatus may be more particularly mentioned the corpus callosum, the fornix, the anterior, the posterior, the soft, and the superior longitudinal commissures.

Aspects of the brain.

For the sake of a clear conception of the structure of the brain, so far as is required for physiological purposes, the annexed representations of its superficial aspects are given. These are a preparation for the diagrammatic sketches which follow, and which enable us to understand the relation and dependence of the more prominent parts. It need scarcely be added that the uses and functions of nearly all the subordinate parts are at present wholly unknown. For the time being, they are therefore objects of interest to the anatomist rather than to the physiologist.

Fig. 154, external lateral face of the right half of the brain: 1, medulla oblongata; 2, pons varolii; 3, cerebellum; 4, pneumogastric lobule; 5, frontal convolutions; 6, parietal convolutions; 7, occipital convolutions; 8, fissure of Sylvius; 9, 9, its two branches.

Fig. 154.

External lateral face of the brain.

Fig. 155.

Superior aspect of the brain.

Fig. 155, superior aspect of the brain: 1, 1, anterior lobes; 2, 2, posterior lobes; 3, 3, great median fissure; 4, 4, fissures of Rolando; 5, 5, anterior parietal convolutions; 6, 6, posterior parietal convolutions; 7, 7, rudimentary parietal convolutions; 8, 8, frontal convolutions; 9, 9, occipital convolutions.

Fig. 156, internal lateral face of the right half of the brain: 1, half of medulla oblongata; 2, half of pons varolii; 3, half of crus cerebri; 4, arbor vitæ of cerebellum; 5, aqueduct of Sylvius; 6, half of the valve of Vieussens; 7, two of the tubercula quadrigemina; 8, half of the pineal gland; 9, its inferior peduncle; 10, its anterior peduncle; 11, transverse portion of the fissure of Bichat; 12, superior face of the optic tract;

Fig. 156.

Internal lateral face of the brain.

13, its internal face; 14, commissura mollis; 15, infundibulum; 16, portion of pituitary gland; 17, portion of tuber cinereum; 18, pisiform tubercle; 19, locus perforatus; 20, oculo-motor nerve; 21, portion of optic nerve; 22, anterior cerebral commissure; 23, foramen of Monroe; 24, fornix; 25, septum lucidum; 26, corpus callosum; 27, splenium; 28, genu; 29, sinus of the corpus callosum; 30, gyrus fornicatus; 31, internal convolution of the anterior lobe; 32, deep anfractuosity; 33, convolution of posterior lobe; 34, anfractuosity.

Fig. 157.

Base of the brain.

Fig. 157, base of the brain, photographed from a wax cast: 1, 1, anterior lobes; 2, 2, middle lobes; 3, 3, posterior lobes; 4, anterior portion of great median fissure; 5, its posterior portion; 6, 6, fissures of Sylvius; 7, 7, antero-posterior portions of the great fissure of Bichat; 8, tuber cinereum; 9, 9, corpora albicantia; 10, locus perforatus medius; 11, 11, crura cerebri; 12, pons varolii; 13, medulla oblongata; 14, 14, anterior pyramids; 15, 15, olivary bodies; 16, 16, restiform bodies; 17, 17, lateral lobes of the cerebellum; 18, portion of its middle lobe; 19, 19, two small antero-posterior convolutions of the frontal lobe, separated by the groove of the olfactory nerve; 20, oblique convolution, limiting the fissure of Sylvius; 21, convolution of the great cerebral fissure; 22, olfactory nerve; 23, its bulb; 24, 24, optic nerves and their chiasm; 25, 25, oculo-motor nerves; 26, 26, pathetici; 27, 27, great and small roots of the trifacial; 28, 28, external oculo-motor nerves; 29, 29, facial nerves; 30, 30, auditory; 31, 31, glosso-pharyngeal; 32, 32, pneumogastric nerves; 33, 33, spinal accessory; 34, 34, great hypoglossal. In this engraving several of the symmetrical numbers are not repeated, for the sake of clearness.

Fig. 158 is an analytical diagram of the brain in a vertical section (from Mayo). It serves to impress on the mind the foregoing structural descriptions. *s*, Spinal cord preparing for bifurca- Structure of the brain.

Fig. 158.

Diagram of the structure of the brain.

tion; *r*, restiform bodies passing to *c*, the cerebellum; *d*, corpus dentatum of the cerebellum; *o*, intercalation of the olivary body; *f*, columns continuous with the olivary bodies and central part of the medulla oblongata, and ascending to the tubercula quadrigemina and optic thalami; *p*, anterior pyramids: *v*, pons varolii; *n*, *b*, tubercula quadrigemina; *g*, geniculate body of the optic thalamus; *t*, processus cerebelli ad testes; *a*, anterior lobe of the brain; *q*, posterior lobe of the brain.

Fig. 159, the motor tract (from Sir C. Bell). A, A, fibres of the hemispheres converging to form the anterior portion of the crus cerebri; B, the same tract when passing the crus cerebri; C, the right pyramidal body, a little above the point of decussation; D, the remaining part of the pons varolii, a portion having been dissected off to expose B. 1, olfactory nerve in outline; 2, union of optic nerves; 3, 3, motor oculi; 4, 4, patheticus; 5, 5, trigeminus; 6, 6, its muscular division; 7, 7, its sensory root; 8, origin of sensory root from the posterior part of the medulla oblongata; 9, abducens oculi; 10, auditory nerve; 11, facial nerve;

Fig. 159.

The motor tract.

12, eighth pair; 13, hypoglossal; 14, spinal nerves; 15, spinal accessory of right side, separated from par vagum and glosso-pharyngeal.

Fig. 160 (on the following page), the sensory tract (from Sir C. Bell). A, pons varolii; B, B, sensory tract separated; C, union of posterior columns; D, D, posterior roots of spinal nerves; E, sensory roots of the fifth pair.

The sensorium.

The ganglia at the base of the brain are regarded by Dr. Carpenter as constituting the true sensorium, a doctrine which he has established by many weighty arguments, and which is doubtless one of the most important thus far introduced by any physiologist.

The idea here intended to be conveyed is, that the thalami, striata, sensory ganglia, and nervous arrangements below, constitute an isolated apparatus; distinct from which, and superadded, are the cerebral hemispheres.

From observations on the animal series, the conclusion seems to be un-

Fig. 160.

The sensory tract.

avoidable that the chain of ganglia now under consideration must constitute a sensorium, the centripetal fibres communicating their impression and motion ensuing, the impressions being attended with consciousness. This view is moreover substantiated by observations made after excision of the cerebrum, a certain degree of consciousness remaining, not unlike that exhibited by a man who is half asleep. This condition of things is naturally presented in the amphioxus.

Effect of the addition of the cerebrum.

But after the cerebral hemispheres are added, an impression received upon the thalamus, whether it has come in through the sensory ganglia, or any other sensory part of the cranio-spinal axis, is transmitted to the convolutions along the radiating fibres. From the convolutions, the influence which is to produce motion descends along the converging fibres to the striatum, thence along the inferior layers of the crus, through the mesocephalon to the anterior pyramids, and by their decussation to the opposite side of the cord.

Such is the view which Dr. Carpenter presents of the functions of the sensory ganglia and spinal axis; or, employing the terms we have previously defined, the cord alone is a longitudinal series of automatic arcs; on the addition of the thalamus and striatum, it becomes a compound registering arc, the cerebral hemispheres finally annexed to it constituting an influential arc.

In a simple arc, an impression is at once converted into motion, and leaves behind it no traces; its expenditure is instantaneous and complete. In a registering arc, a part of the impression is stored up or remains—

nay, even the whole of it may be so received and retained. It is not to be overlooked that, as soon as this effect occurs, the evidences of sensation arise; and, since sensation necessarily implies the existence of ideas, ideas themselves are doubtless dependent on this partial retention or registry of impressions. We may therefore adopt the doctrine of Dr. Carpenter, as regards the sensorial functions of the cranio-spinal apparatus, not only from the arguments he has presented, but also from other considerations.

General result of variations in the size and weight of the hemispheres.

There can be no doubt that the cerebral hemispheres constitute the instrument through which the mind exerts its influences on the body. Any injury of sufficient severity inflicted upon them is at once attended with a total loss of intellectual power; any malformation or lesion by disease is attended by a deterioration below the customary mental standard; any unusual development with correspondingly increased powers of intellection; and this not only as regards animals of different tribes, or individuals at special periods of their lives, but also of different men when compared with one another. The general impression is founded in fact that those who have distinguished themselves for mental attainments or intellectual power have been marked by the unusual development of their cerebral hemispheres.

Instrumental nature of cerebrum.

It is to be understood that, in thus asserting a correspondence between the development of the cerebrum and intellectual capability, we are not to overlook the instrumental nature of that organ. Though imperfections in it may produce a manifest inferiority, that inferiority is by no means to be referred to the intellectual principle itself. The mode of action being by an instrument, if that instrument becomes imperfect the action becomes imperfect too. Under such circumstances, in any human contrivance, we should never think of imputing inferiority to the prime mover.

From this point of view we may therefore consider the intellectual principle as possessing powers, properties, and faculties of its own; as being acted on by impressions existing in the thalamus, and delivered through the intervening fibrous structures to the vesicular material of the convolutions of the cerebral hemispheres. In this region they act upon the intellectual principle and are acted upon by it, the returning influence, if any, coming down through the converging tubular structures to the corpus striatum, and by its commissural connections sent off to particular ganglia, passing along the inferior strand of the crus through the mesocephalon to the anterior pyramids, and by their decussation to the opposite side of the cord.

Having thus spoken of the sensory ganglia and the cerebral hemispheres, it remains to add some remarks respecting the cerebellum. It

The cerebellum. arises, as has been stated, from the triple strand of the crus cerebelli, of which one layer of fibres is connected with the corpora quadrigemina, and through them with the optic thalami; a second with the restiform bodies; and the third is commissural, and passes forward as the pons varolii.

Like the cerebrum, this organ is vesicular on its surface, which presents a number of parallel lines, which are fissures descending to the interior. Their object is apparently the same as that of the convolutions of the brain, the augmentation of surface. Of these fissures, the deep are termed the primary: they divide the organ into lobes. Those which descend to a less depth are termed secondary: the divisions they give rise to are lobules. The gray vesicular material does not, however, descend to the bottom of the primary fissures, and in this respect they differ from the cerebral convolutions. Moreover, from this circumstance, that material is not continuous all over the cerebellum, but is in divided portions.

Such are the appearances presented on an exterior examination of the cerebellum. Viewed as a development upon the crura cerebelli, it may be described as consisting of a median lobe and two hemispheres; the former is, however, found existing alone in fishes and reptiles, the latter being subsequently added in the higher tribes. From the central column of each hemisphere white fibrous planes are given off, and from these, again, secondary, and again, tertiary planes proceed. The planes are covered with vesicular matter, and thus give rise to the appearance spoken of in the preceding paragraph, in the exterior examination of the cerebellum, as primary and secondary fissures. They are lined with pia mater. The median lobe is formed on the same plan. Its fibrous stem comes from the processus cerebelli ad testes, or, more properly, from the optic thalamus. The weight of the cerebellum, compared with that of the cerebrum, is usually stated as being about 1 to 8.

Structure of the cerebellum.

Much diversity of opinion prevails respecting the true function of the cerebellum, some supposing that it is the centre of common sensation, others that it is for the purpose of co-ordinating muscular movement, and others that it is the seat of sexual instinct.

That the cerebellum is one of the sensory ganglia may be inferred from the history of its development and its anatomical connections. Its median lobe is the first to appear, as in fishes, and the hemispheres arise subsequently as appendages thereto, as in birds. The size which these eventually attain gives them a deceptive prominence, and hides their subordinate character. Regarding the lobe, therefore, as the essential and fundamental portion of the structure, the significance of its cerebral connection with the thalamus through the processus ad testes is too obvious to be overlooked. As by this its senso-

Function of the cerebellum.

ry character is displayed, so the same holds good for the hemispheres, their relations with the spinal cord through the restiform bodies being also of a sensory nature. It seems probable that the superficial vesicular material is in anatomical connection with the thalamus, and the corpus dentatum or inner ganglia with the posterior or sensory columns of the cord.

The doctrine that it co-ordinates muscular motion.

The arguments which have been brought forward by those who suppose the cerebellum to have for its office the co-ordination of general muscular movement, may be briefly quoted as follows: There appears to be a general correspondence between its size and the degree of energy and complication of the motor powers in various animals. Thus, in fishes, and likewise in birds, those tribes which excel in their powers of motion, or are distinguished by the complication of their movements, are characterized by the manner in which this organ is developed; and the same may be said even of the mammalia, quadrupeds whose locomotive mechanism is simple possessing it in a lower state of development than those which either temporarily or constantly move on the posterior extremities. Among apes, those which more frequently assume the erect posture, which is normal to man, have their cerebellum of a size more closely approaching to his.

On examining such facts, it appears that it is not so much muscular power as the quality of co-ordinating and governing minute muscular motions. To maintain the standing position motionless, there are, in reality, a great many muscular movements required, which serve to antagonize all the little incidents producing a tendency to fall; and if this be so in standing, how much more difficult must such antagonizing and compensating actions become in walking, running, and such movements. Theoretically, it might be expected that some special organ is necessary to combine such various actions, and that organ seems to be the cerebellum.

Results of experiments of the cerebellum.

In confirmation of this are the experimental results which have been obtained. The cerebellum, on irritation, gives rise to no convulsive motions, nor to sensations. If removed by degrees in successive slices, the motions of the animal become irregular, and, finally, it loses all power of walking or of maintaining its equilibrium. Though the powers of the animal in bringing its muscles into contraction seem not to have suffered, it can not co-ordinate or combine the necessary muscular exertions, and, as is graphically stated, staggers and falls over like a drunken man, still making efforts to maintain its balance. Such experiments have been repeatedly made in the case of different animals, and with the same results.

Connected with these results of experimental lesions of the cerebellum are the rotations, as they are termed, which occur, for example, when one

Rotary motions of animals.

of the crura cerebelli is cut, the animal rolling upon its longitudinal axis for a long time and with great rapidity. From such facts, it has therefore been concluded that the function of the cerebellum is neither for sensation nor intellection, nor is it the source of voluntary movements, but that it is for the government or control of combined muscular action. This is the view of M. Flourens.

Doctrine that cerebellum is for the perception of muscular sensations.

M. Foville supposes that the cerebellum is for the perception of the sensations derived from the muscles, and enabling the mind to exert a guiding action. The facts which support the preceding view support this also, there being, moreover, in this case, an additional argument derived from the connection which the cerebellum has been shown to maintain with the sensory columns of the cord, and the pain experienced on irritating the restiform columns. It has likewise been pointed out that this hypothesis illustrates the connection between the cerebellum and the optic ganglia, as if it were for the purpose of bringing the organs of sight to the aid of this co-ordination of muscular motion.

Doctrine that it is the organ of amativeness.

A third hypothesis, to which allusion has been made, is, that the cerebellum is the organ of sexual instinct, or of amativeness, as it is termed by phrenologists. The evidence of this, when fairly examined, is, however, very far from affording a full proof; indeed, in many instances the facts are in direct opposition to the doctrine. In castrated animals the cerebellum undergoes no diminution. There is no coincidence between the intensity of that instinct in the different animal tribes and the degree of development of this organ; and where it has been in a diseased condition, there has not been a necessary correspondence between the lesion and the loss of the instinct.

Phrenology.

This view of the function of the cerebellum is connected with the doctrine of special localization, or phrenology, which may therefore be here briefly considered; the general expression of this doctrine being that particular regions of the brain are devoted to special functions, and that by an inspection of the exterior of the cranium mental peculiarities may be detected. Drs. Gall and Spurzheim considered that this view is supported by the fact that the specialization of function in the brain is agreeable to the general mechanism of the system, in which particular organs are charged with particular duties; that, in any individual, the mental powers are not equally or proportionally developed, but some at one and some at another period of life, and so likewise of their decline, some remaining at their original strength, while others may have become seriously impaired. It does not appear how such facts can be explained upon the hypothesis that the whole brain acts as a unit. They may be readily understood if it be supposed to act by parts which are developed in succession. The

Arguments in proof of special localization of functions.

same conclusion is arrived at from well-known facts connected with insanity, in which it very frequently happens that some of the faculties alone are deranged, while the others retain their power, and some may even become more perfect than before; so, likewise, in dreaming, some of the faculties retain their activity, while others have become torpid; and so, likewise, when different individuals are compared, some exhibit a superiority in one, and some in another mental particular; and it is asserted that where the same peculiarity has predominated in different individuals, it has always been attended by an unusual development of a special locality of the brain. Nor is there, in these views, any thing that stands in contradiction to the general plan upon which the nervous system itself is constituted, as is manifested by the different sensory ganglia for vision, hearing, or smell, or the arrangement for motion or sensation presented by the spinal cord; and, moreover, they are supported by the comparative anatomy of this system; for, whatever grade of animal life we may consider, the appearance of a new function or of a new instinct is certain to be connected with a new and contemporaneous development of some part of the nervous system.

The facts which have been observed in cases where one cerebral hemisphere has either suffered lesions or lost its functions, do not present any contradiction to the preceding doctrines; for, though the remaining hemisphere may seem to act equally well alone, as did both together, we are very apt to deceive ourselves as regards the actual facts, a statement which may be illustrated by recollecting how easily we persuade ourselves that we see with one eye as well as with two. No doubt, in many of the ordinary cases, one hemisphere of the brain may, like one eye, seem to act well enough, but a more critical examination proves that in other cases this is far from being true. That the two hemispheres act severally and separately is clear from what sometimes ensues in diseased conditions of one of them, or when, perhaps, there is a want of symmetry between them, those remarkable forms of mental derangement, sometimes known under the designation of double life or duality of mind, then ensuing.

Weight of the brain.

In man, the weight of the brain averages about fifty ounces; in females, about forty-five; the maximum being about sixty-four, and the minimum about twenty; in the case of idiots, the mean specific gravity of the gray matter is stated by Dr. Sankey to be, in both sexes, 1.034, but somewhat less early and late in life. The specific gravity of the white is 1.041, and this varies less with sex and time of life than the former.

The functional activity of the brain depends on the copious supply of arterial blood. It is computed that one fifth of the whole quantity in the circulation is sent to this organ. It is delivered through the two

Supply of blood to the brain.

internal carotid and two vertebral arteries. The impetus of the current is checked by the sinuous course these vessels take, or by their breaking promptly into capillary branches. A freedom of anastomosis among them, as is well displayed in the circle of Willis, affords abundant provision for accidental stoppages or restraints.

Atmospheric pressure on the brain.

Although the brain is inclosed in an unyielding cavity, it is subject to the pressure of the air, a fact which, though it has been denied by some physiologists, follows from ordinary physical principles. And since the quantity of blood present at any moment in the organ varies with the contemporaneous functional activity, being greater as that activity is greater, the cerebro-spinal fluid also varies in amount. Through this fluid an equality of pressure is therefore insured, no matter what may be the quantity of blood in the brain.

Cerebro-spinal fluid.

The cerebro-spinal fluid, the quantity of which has been estimated at two ounces, is readily absorbed and as readily reproduced. The act of adjustment between it and the blood requiring a certain period for its completion, the brain can not instantaneously be brought to its maximum action. Thus, as all persons observe, when we undertake any unusual intellectual duty, there is a certain preparatory period to be passed through, as the common expression is, "for composing the thoughts."

Effect of mechanical pressure and changes in the blood.

Pressure upon the brain, either applied mechanically or through accidental effusions, produces at once functional inactivity, probably by interference with the due circulation of the blood; and, in like manner, any marked change in the chemical relations of that fluid exerts on the brain a corresponding effect. Thus, when oxygen gas is breathed, or, still better, protoxide of nitrogen, which is more soluble in the blood, the processes of intellection go on in an exaggerated way, and ideas in rapid succession, and in unusual forms of combination, flit through the mind; but, as the consequence of this, since the lungs can not remove with the necessary promptness the carbonic acid which is arising, the narcotic effects of that body are soon experienced; and this is also the case in alcoholic intoxication, in the advanced stages of which the accumulation of carbonic acid in the blood gives rise to the same result.

Effect of size and elaboration of the brain.

That different regions of the brain have independent though mutually commissured faculties, is fully established by the phenomena of the nerves of sense, nor can there be any doubt that these differences of physiological function are directly dependent on differences of anatomical structure. It is, indeed, to structural differences that we should impute the greater or less efficiency of the whole organ, as much as to differences of its weight. Because of a higher elaboration,

the brain of one person may be more energetic than that of another, even though its weight may be less. It is not to be denied, however, that there is a connection between mental power and the quantity of cerebral matter, when individuals of the same kind are compared, or that in the animal series the psychical powers decline as the cerebrum diminishes in size.

Its variable psychical powers.

Few topics are more worthy of the attention of the physiologist than that of the variable psychical powers of man, and yet few have been more overlooked. By variable psychical powers I mean those periodicities of increase and diminution in our intellectual efficiency, which may be noticed not only in diseased, but also in healthy states. On the principles we have presented, these find their explanation in the temporary physical states of the organ, such as its condition of repair, its existing facility for oxidation, and the constitution of the blood as respects a proper arterialization.

Symmetrical doubleness of nervous system.

The most striking structural characteristic of the nervous system is its symmetrical doubleness, the cranial and spinal nerves coming forth by pairs to their distribution on the right and left sides of the body. The manner of development from the spinal axis laterally implies such a construction, and, indeed, gives origin to two halves so equal and alike that it has often been said each person consists of two separate individuals. Examining those organs which, by reason of the elaborateness of their mechanism and principles of action, enable us to determine with satisfactory precision the function discharged by each one of the members of the pair, as in the case of the eye or the ear, we may come to the following conclusions: Each is a distinct organ in itself, capable of its meeting the requirements of the economy in a sufficiently satisfactory manner, and therefore forms a distinct whole; but the pair can likewise act simultaneously, re-enforcing, to a certain degree, each other's power, though in this double action there by no means arises a double intensity of effect. The closure of one ear to a sound does not diminish the loudness by one half, nor does the shutting of one eye reduce to one half the brightness of a light; but, though there is not such a doubling of effect when both eyes or both ears are employed, there is a degree of precision in the resulting indication which is not to be gained by the use of one of these organs alone. In such a double organ, then, the result is not so much a heightening of the final impression as the giving to it of a greater degree of precision.

Function of each lateral organ.

Conjointly double organs do not double effects, but increase their precision.

Compensation of defects.

Moreover, each organ seems to exert a compensating influence over its fellow in any deficiencies or imperfections it may possess. Thus it is rare that both eyes are of an equal optical goodness, as most individuals will find on making a personal examination;

but in vision with both eyes the faults of the more imperfect one are merged in the indications of the better, and the same might be remarked of the ear; from which it would appear that this doubleness of organs is rather for the purpose of introducing a principle of compensation than one of conspiring action, the object intended to be gained being a justness of perception rather than an increase of effect.

These observations apply to double organs in their normal states, or, if not their normal, their habitual ones; but if to the eye, for example, a temporary disturbance is given, as by pressure which renders its optical axis oblique, the fellow organ being permitted to retain its usual position, double sight is the result. It is true that, in the habitual divergence of strabismus, such is not the effect, one of the images disappearing, or perhaps the mind, accommodating itself to the habitual condition, combines the two into one. These circumstances indicate that each member of a double organ can, under conditions of disturbance, exercise an independent and even opposing action to its fellow.

Effect of temporary disturbance of one organ.

It has by some been supposed that the mind pays attention to the impressions of only one of the pair of organs at a time; thus, that we see the images furnished by only one eye, though we can with very great quickness direct attention to those furnished by the other, and therefore, deceived by the rapidity with which this alternation of attention can be accomplished, our belief in the synchronous use of both organs is an error. If two differently colored objects, such as differently tinted wafers, be so placed as to be separately and yet simultaneously viewed by both eyes, the mind vainly attempts to combine the two images together. We do not see the resulting form of a green tint, but we see, according as our attention is given to the right or left, a blue or a yellow, if these have been the colors of the wafers, and these colors can quickly merge into one another, like dissolving views. There is a simple experiment which serves to support this view, and which any one may readily make. If the open hand be placed along the nose, so as to divide the right eye from the left, and we look upon the surface of a uniformly-illuminated sheet of paper covered with writing, it will be found that we can only read with one eye at a time, but that the mind can with great rapidity determine which eye it will use. In this little experiment, we have, moreover, the means of estimating the relative sensitiveness of the two eyes, and other of their optical peculiarities; thus it will be commonly remarked that, though the paper be, as we have said, uniformly illuminated, that part of it which is regarded by one eye is brighter than that seen by the other, this being due to a difference in their sensibility. It will also frequently occur that the two portions of the page will present different shades of tint,

The indications of one organ contemplated at a time.

Illustrative experiment.

he one, perhaps, being a faint greenish gray, while the other is of a yel-
owish white, the proper color given to it by the candle or lamp by which
is seen.

In this feature of double construction the brain itself participates, pre-
enting a right and left half approaching one another in form, without
eing absolutely identical. Much, therefore, of what has been said re-
pecting the mutual relations of the right and left eye, and the right and
eft ear, must apply to the right and left hemispheres of the brain; and
t is under this point of view that Dr. Wigan has regarded it in
is work on the Duality of the Mind. Nor can there be any
oubt that each hemisphere is a distinct organ, having the
ower of carrying on its functions independently of its fellow; that, though
ach can thus act separately, both can act simultaneously; and, judg-
ng from the cases that have just been presented, it would seem that we
re justified in inferring that the common action of the two hemispheres
s not for the purpose of a heightening of effect, but only for greater pre-
ision, and that in the same manner as it is a rare thing to find two eyes
r two ears of equal goodness, so also it is unusual to have two hemi-
pheres which are precisely alike. The defects of the one may
e compensated by the superiorities of the other, and thus
mean result be attained; and as one eye or one ear can,
nder the proper circumstances, overpower its fellow, so likewise can one
emisphere of the brain, except in certain cases, which have been some-
hat imaginatively described as insubordination of one of the hemi-
pheres, when insanity is the result, the healthy half being unable to
ontrol the diseased one; and for this reason, we often observe of the
nsane that they have synchronously, or, at all events, in a very rapid al-
ernation, two distinct trains of thought, and, consequently,
wo distinct utterances, each of which may, so to speak, be
erfectly continuous and even sane by itself, but the incongruities that
rise from the mingling of the two betray the condition of such persons.
n this case doubleness of action is seen in its most exaggerated aspect,
ut in a less degree, it may be remarked, in the thinking operations of
hose whose minds are perfectly sound. Thus there is no student but
ust have observed, when busily engaged in reading, that his mind will
ander off to other things, though he may mechanically cast his eyes
ver page after page; and the same may occur in listening to a lecture
r sermon. But, though the insane man may indulge in two synchro-
ous trains of thought, he never indulges in three, for the simple reason
hat he has not three hemispheres to do it with, the same remark apply-
ng to the sane man in the accidental wanderings of his thoughts.

The overcoming of this insubordination of one of the hemispheres may,
o a very considerable degree, be accomplished by education, of which

Independent action of each hemisphere.

Insubordination of one hemisphere.

Double train of thought.

Effect of education. one of the chief results is that it exercises us in the habit of thinking of one thing at a time, of thinking therefore without confusion, and of arriving at conclusions with precision and decision. And these considerations should also, in Dr. Wigan's view, be our chief guide in the cure of insanity, doing all in our power to invigorate the action of the healthy hemisphere, and enable it to subdue the insubordination of the diseased one. If both hemispheres are diseased, the case is almost hopeless.

Of the independent and yet complete action of each of the cerebral hemispheres we have abundant and interesting proof. Perfect action of a single hemisphere. Mental operations can be carried on in a profoundly diseased state of one of these organs, as multitudes of well-authenticated cases attest—nay, even when the lesion has gone so far as to amount to an absolute and entire disorganization of one of the hemispheres. Similar evidence is also furnished by those interesting cases in which, by accident, as by gunshot wound, destruction of one side has occurred.

Even in a state of health we have numerous examples of this independent action of each hemisphere. Intermixed action of the two hemispheres. While engaged in ordinary pursuits which imply a continued mental occupation, we are occasionally troubled with suggestions of a different kind. A strain of music, or even a few notes, may be perpetually obtruding, and such an occurrence we could scarcely explain save upon the principle of the separate action of these organs, the one interfering with the other. That precision which we have remarked as arising from the conjoint use of two eyes and two ears is doubtless also attained where the two hemispheres are acting in unison. We can, moreover, voluntarily permit one to rest while the other continues its duty, as we can voluntarily make use of one eye, disregarding the indications of the other; but where it is necessary to execute a critical comparison or arrive at an accurate judgment of things, both hemispheres are brought into action, as are both eyes when we intently consider an object.

Among other phenomena, Dr. Wigan calls attention to the operation Castle-building. of castle-building, as it is designated, as illustrating the voluntary manner in which we permit one hemisphere to act, presenting fanciful delusions; the other, as it were, watching with satisfaction the operation, and in this respect lending itself to it. Not that for a moment we suppose there is any truth in the ideas suggested, and in this the phenomenon differs essentially from that of dreaming, in which it never occurs to us that the scenes and actions are unsubstantial.

Still more strikingly do those singular cases, which from time to time present themselves to the physician, Double or alternate consciousness. of double or alternate consciousness, illustrate this isolated function of the hemispheres. In some of these, which have been carefully ob-

served and authentically recorded, each of these portions of the brain has continued its action for a period of days, or even weeks, and then, relapsing into a quiescent state, has been succeeded by the other, thus presenting in some degree an analogy of what is observed in ordinary cases of insanity, so far as the reciprocating action of the two organs is concerned, but differing in the period of duration of their function; and thus, if one of them should have undergone deterioration, or have suffered lesion, so that it has been reduced to what might be termed an infantile state, the impressions formerly stored up in it having been for the most part lost, or there being an incapacity in it to make use of them, the patient will alternately exhibit what has been aptly termed child life and mature life. For a few days, or perhaps weeks, he will conduct himself in the ordinary manner of an adult, reading, reasoning, and acting, and then, for a similar period, will pass into a condition in which he does not even know his letters, and reasons and acts like a child. These phenomena of alternate and double intellection are interesting in the highest degree, and seem to be explicable on no other principle than that which this author suggests.

Sentiment of pre-existence.

But I do not think that the explanation which he offers of the sentiment of pre-existence is correct. By this term is understood that strange impression, which all persons have occasionally observed in the course of their lives, that some incident or scene at the moment occurring to them, it may be of quite a trivial nature, has been witnessed by them once before, and is in an instant recognized. Though this opinion that we have seen a present incident once before sometimes occurs in cases where the circumstances are of profound interest to us, the experience of most persons assures us that it is more frequently in trivial events. Dr. Wigan's view is, that it arises from the almost contemporaneous action of the two hemispheres, and that, under the circumstances, we have a confusion of memory, and are led to believe that there has been an interval of indefinite duration, when, in point of fact, it was an impression in each hemisphere closely coincident in point of time. This explanation turns on the assumption that this sentiment of pre-existence occurs but once. He denies that we ever suppose that we have seen the thing twice before. But I believe that the experience of many individuals assures them that this is not the case, and that they are under a firm persuasion that they have witnessed the same incidents more than once before, nay, perhaps even many times. The instance which this author furnishes as occurring to himself, in which, on the occasion of attending the funeral of an exalted personage, and at the time of the coffin being deposited in the vault, with the striking solemnities of the occasion there rushed upon his mind the idea that he had been present at this same scene once before, a thing which was,

of course, an impossibility, is very instructive. But the difficulty in the way of his hypothesis lies in the fact that it offers us no explanation of those cases in which we are perfectly persuaded that we have witnessed the thing more than once before, though it may answer in the particular instance here cited. Perhaps we may appropriately recall the well-known fact offered to us in dreaming, and to which attention hereafter will be more particularly directed, that there are circumstances under which our mental operations are carried forward with the most marvelous speed. Thus a sudden sound, which awakes us, or even a flash of lightning, which is over in a moment, may be incorporated or expanded into a long dream, diversified with a various multitude of incidents, all appearing to follow one another in an appropriate order, and occupying, as we judge, quite a long time, yet all necessarily arising in an instantaneous manner, for we awake at the moment of the disturbance. Of the same kind is that remarkable deception, which is authentically related by those who have recovered from death by drowning, that in the last moment of their agony all the various events of their past life, even those of a trivial kind, have come rushing before them with miraculous clearness. Mental operations, therefore, both as regards old recollections and new suggestions, may take effect with wonderful rapidity, and if the sentiment of pre-existence is to be explained on the principle of the double action of the brain, it must likewise be dependent upon the fact here presented.

Loss of a true perception of time.

CHAPTER XVII.

OF THE CRANIAL NERVES AND THE GREAT SYMPATHETIC.

Enumeration of the Cranial Nerves.—The Third Pair, or Oculo-motor.—The Fourth Pair, or Pathetici.—The Fifth Pair, or Trigemini.—The Sixth Pair, or Abducentes.—Illustrations of the Third, Fourth, Fifth, and Sixth Pairs.—The Seventh Pair, or Facial.—Illustration of the Facial.—The Ninth Pair, or Glosso-pharyngeal.—Illustration of the Glosso-pharyngeal.—The Tenth Pair, or Pneumogastric.—Illustration of the Pneumogastric.—Illustration of the Laryngeals.—The Eleventh Pair, or Spinal Accessory.—The Twelfth Pair, or Hypoglossal.—Illustration of the Hypoglossal.

The Phrenic Nerve.

Of the Great Sympathetic System.—Position, Structure, and Origin of the Sympathetic.—Its Relation with the Pneumogastric.—Its Connection with the Spinal System.—Its Plexuses.—Its Ganglia.—They are Reservoirs of Force.—Summary of the Functions of the Sympathetic.—Illustration of the Sympathetic.—The Abdominal Plexuses.—The Solar Plexus.—The Mesenteric Plexuses.

The cranial nerves.

THERE are twelve pairs of cranial nerves: 1st. The olfactory; 2d. The optic; 3d. The oculo-motor; 4th. The pathetic; 5th. The trifacial; 6th. The abducent; 7th. The facial; 8th. The auditory; 9th. The glosso-pharyngeal; 10th. The pneumogastric; 11th. The spinal accessory; 12th. The hypoglossal.

Of these, the first, the second, and the eighth, being nerves of special sensation, may be more conveniently studied in connection with the organs of special sense—the nose, the eye, the ear.

OF THE THIRD PAIR, OR OCULO-MOTOR NERVES.

The third pair, or oculo-motor.

The motor-oculi nerve arises from the inner side of the crus cerebri, near to the pons varolii, some of its fibres passing into the gray substance of the crus. Advancing forward, it divides into two branches, one of which supplies the superior rectus and levator palpebræ, the other the internal rectus, inferior rectus, and inferior oblique. Considering the place of origin, it would be expected that this nerve is wholly motor, and this is confirmed by experiment. When the nerve is irritated the muscles which it supplies are convulsed, and when it is divided they are paralyzed. Through its connection with the lenticular ganglion, it furnishes motor filaments to the iris. The optic nerve, the corpora quadrigemina, and this nerve together constitute a complete nervous arc, and impressions made on the retina occasion motions in the iris.

OF THE FOURTH PAIR, PATHETICI, OR TROCHLEAR NERVES.

The fourth pair, or pathetici.

This nerve arises from the valve of Vieussens, near the testis, and, passing around the crus cerebri, enters the orbit, and is distributed to the orbital surface of the superior oblique, or trochlear muscle, for which it is the motor nerve. When it is irritated that muscle is convulsed.

OF THE FIFTH PAIR, TRIFACIAL, OR TRIGEMINI.

The fifth pair, or trigemini.

The fifth nerve has a construction so closely analogous to that of the spinal nerves, that it has been designated the spinal nerve of the head. It arises by two roots, the anterior of which is the smaller, the posterior having a large ganglion, the ganglion of Gasser; with this ganglion the anterior root is in contact, but not in connection: it passes forward to the inferior maxillary nerve. From the ganglion three branches diverge, the ophthalmic, the superior maxillary, and inferior maxillary, the first proceeding from the upper angle of the ganglion, the second from the middle, the third from the inferior angle. This last receives the motor portion of the nerve; the first and second branches are sensory, the third is sensory and motor also. From the sensory portions the anterior and most of the antero-lateral portions of the head are furnished, as also the organs of special sense themselves, so far as their common sensation is concerned. The motor branch supplies the muscles of mastication.

OF THE SIXTH PAIR, OR ABDUCENTES.

The sixth pair, or abducentes.

This nerve arises by several filaments from the upper part of the corpus pyramidale, near to the pons varolii, and is distributed to the external rectus. From its origin, distribution, and from experiments made upon it, it is known to be a motor nerve.

ILLUSTRATIONS OF THE THIRD, FOURTH, FIFTH, AND SIXTH PAIRS OF NERVES.

Fig. 161.

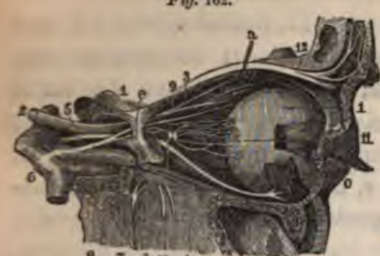
Nerves of the orbit.

Fig. 161: 1, chiasm of optic nerves; 2, third pair; 3, nasal nerve; 4, external oculomotor; 5, ganglion of Gasser; 6, nasal nerve and its two branches, internal and external; 7, nerve of obliquus inferior; 8, ophthalmic ganglion; 9, ciliary nerves; *a*, portion of levator palpebrae superioris and rectus superior; *b*, rectus internus; *c*, rectus externus; *d*, fibrous ring of the recti muscles.

NERVES IN THE ORBITAL CAVITY.

Fig. 162: 1, 1, optic nerve and globe of the

Fig. 162.



Nerves in the orbital cavity.

eye; 2, third nerve; 3, superior branch; 4, nerve of obliquus inferior; 5, external oculo-motor; 6, ganglion of Gasser; 7, ophthalmic branch; 8, nasal nerve; 9, ophthalmic ganglion; 10, short root of ophthalmic ganglion; 11, ciliary nerves; 12, frontal nerve; *a*, levator palpebræ superioris and rectus superior; *b*, rectus inferior; *c*, obliquus inferior; *d*, rectus externus; *e*, ring of the recti muscles.

DIAGRAM OF THE FIFTH NERVE.

Fig. 163.

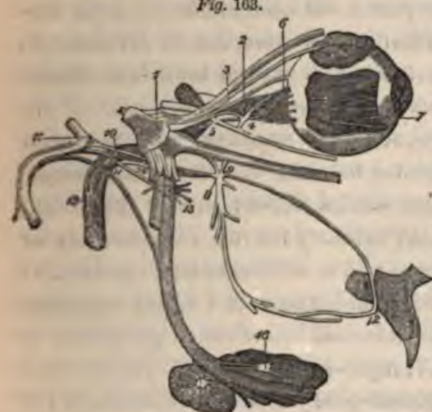


Diagram of the fifth nerve.

Fig. 163: 1, ganglion of Gasser; 2, ophthalmic ganglion; 3, its long root furnished by the nasal branch; 4, short root; 5, sympathetic, from the plexus surrounding the internal carotid; 6, ciliary nerves traversing the sclerotic; 7, ciliary ganglion; 8, ganglion of Meckel; 9, its sensory roots from the superior maxillary; 10, petrous branch of vidian nerve, or motor root of the ganglion of Meckel; 11, its sympathetic root; 12, naso-palatine ganglion, receiving at its upper angle the naso-palatine nerve, and at its inferior the anterior palatine; 13, otic ganglion; 14, small superficial petrosal; 15, submaxillary ganglion; 16, sublingual ganglion; 17, geniculated ganglion; 18, cavernous ganglion.

GANGLION OF GASSER AND ADJACENT PARTS.

Fig. 164.

Ganglion of Gasser.

Fig. 164: 1, ganglion of Gasser; 2, ophthalmic nerve; 3, frontal branch; 4, lachrymal; 5, nasal; 6, opthalmic ganglion; 7, superior maxillary nerve; 8, orbital branch; 9, ganglion of Meckel; 10, petrosal branch of vidian nerve; 11, palatine nerves; 12, anastomosis of the ganglion of Meckel with the nervous plexus surrounding the internal maxillary artery; 13, posterior and superior dental nerves; 14, suborbital nerve, its anastomoses wi

and nasal; 15, inferior maxillary, receiving the motor portion of the fifth pair; 16, superficial auriculo-temporal nerve; 17, buccal nerve; 18, section of other collateral branches of inferior maxillary; 19, inferior dental; 20, mental nerve; 21, lingual; 22, chorda tympani; 23, facial nerve; A, external carotid artery; B, facial artery; C, temporal artery; D, internal maxillary; E, its dental branch; F, middle meningeal; *a*, membrana tympani; *b*, glenoid cavity; *c*, orbicularis oris; *d*, buccinator; *e*, pterygoideus internus; *f*, pterygoideus externus; *g*, digastric; *h*, sterno-cleido-mastoid muscle.

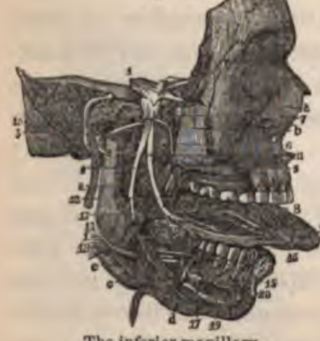
THE FIFTH NERVE, THE GANGLION OF GASSER BEING REMOVED.

Fig. 165.

The fifth nerve.

Fig. 165: 1, ophthalmic, cut; 2, superior maxillary, cut at both extremities; 3, ganglion of Meckel; 4, petrosal and carotid branch of vidian nerve; 5, abducent; 6, nerve of Jacobson; 7, superior and posterior dental nerves; 8, anterior and superior dental nerve; 9, otic ganglion; 10, gustatory nerve; 11, chorda tympani; 12, submaxillary ganglion; 13, anastomosis of lingual with hypoglossal; 14, sublingual plexus; 15, terminal branches of gustatory or lingual nerve; 16, inferior dental; 17, mylo-hyoid branch; 18, mental; 19, incisive nerve; 20, ganglion of glosso-pharyngeal; 21, facial, in the aqueduct of Fallopius; 22, hypoglossal; *a*, superior maxillary bone; *b*, cartilages of the nose; *c*, internal wall of tympanic cavity; *d*, pterygoideus internus muscle; *e*, buccinator, cut; *f*, mylo-hyoid muscle; *g*, part of anterior belly of digastric; *h*, sterno-cleido-mastoid, turned aside.

Fig. 166.



The inferior maxillary.

ILLUSTRATION OF THE TERMINAL BRANCHES OF THE INFERIOR MAXILLARY NERVE.

Fig. 166: 1, motor and sensory roots of ganglion of Gasser; 2, junction of motor root with inferior maxillary; 3, auriculo-temporal nerve; 5, buccal nerve; 6, pterygoid nerves; 7, cut branches of temporal and masseteric nerves; 8, gustatory nerve; 9, chorda tympani; 10, facial; 11, anastomosis of gustatory and inferior dental nerves; 12, tonsillar branch; 13, submaxillary ganglion; 14, sublingual plexus; 15, anastomosis of gustatory and hypoglossal nerves; 16, branches

of gustatory; 17, inferior dental; 18, mylo-hyoid nerve; 19, incisive branch of dental nerve; 20, branch of mental, cut; *a*, pterygoideus internus; *b*, part of pterygoideus externus muscle; *c*, mylo-hyoid muscle; *d*, portion of anterior belly of the digastric; *e*, hypoglossal muscle; *f*, portion of submaxillary gland.

OF THE SEVENTH PAIR, THE FACIAL NERVE.

This nerve arises from the upper part of the groove between the olivary and restiform bodies, and near the pons varolii. With the auditory nerve, or portio mollis, it constitutes the seventh nerve in the nomenclature of Willis, and derives the name portio dura, under which it sometimes passes, from the density and closeness of its texture. It supplies all the muscles of the face except those of mastication, which are supplied by the fifth nerve, those of the palate, the stapedius, laxator tympani, and tensor tympani; also the muscles of the external ear, and some of those of the tongue. The facial is a centrifugal nerve. If irritated near its origin, there is no sensation of pain; but subsequently it obtains fibres from other sources, as from the fifth and the pneumogastric. After it has been joined by these, irritation is acutely felt. It is therefore to be regarded as the general motor nerve of the face, influencing the function of respiration through reflex action, but not being connected with the function of mastication. Injury of it produces paralysis of the parts to which it is distributed, as, for example, the orbicularis palpebrarum, causing inflammation of the eye and opacity of the cornea, through inability of that organ to free itself from dust and spread the lachrymal secretion over its surface. In like manner, the sense of hearing may be injured through loss of control over the muscular structures of the ear, and the acuteness of the sense of smell diminished from inability to introduce the air in a strong current, or the sense of taste, if the point of injury be previous to the giving off of the chorda tympani. In paralysis of the facial nerve the muscles of the face become powerless, and the countenance, therefore, distorted.

The seventh pair, or facial.

Fig. 167.

The facial nerve.

ILLUSTRATION OF THE FACIAL NERVE.

Fig. 167: 1, trunk of the facial at its emergence from the aqueduct of Fallopius; 2, occipito-auricular branch; 3, auricular of the cervical plexus; 4, twig of the occipital mus-

cle; 5, twig of the posterior auricular muscle; 6, twig of the superior auricular; 7, anastomosis of the facial with the auricular of the cervical plexus; 8, branch for the stylo-hyoid and posterior belly of the digastric; 9, temporo-facial anastomosis with the superficial auriculo-temporal of the fifth pair; 10, temporal ramifications of the facial; 11, frontal twigs; 12, superior palpebral twigs; 13, middle palpebral twigs; 14, inferior or motor palpebral twigs; 15, suborbital twigs; 16, suborbital plexus; 17, superior buccal; 18, cervico-facial branch; 19, buccal branches, anastomosing with, 20, buccal nerve of fifth pair; 21, mental twigs, forming with, 22, mental nerve of fifth pair, the mental plexus; 23, cervical branches; 24, transverse cervical branch of cervical plexus; 25, parotid branches of the superficial auriculo-temporal; 26, parotid branches of the facial; *a*, frontal muscle; *b*, occipital muscle; *c*, anterior auricular; *d*, superior auricular; *e*, posterior auricular; *f*, orbicularis palpebrarum; *g*, zygomaticus major; *h*, buccinator; *i*, orbicularis oris; *k*, masseter; *l*, parotid gland; *m*, platysma; *n*, stylo-hyoid and posterior belly of digastric; *o*, sterno-cleido-mastoid; *p*, trapezius.

OF THE NINTH PAIR, OR GLOSSO-PHARYNGEAL.

The ninth pair, or glosso-pharyngeal.

This nerve arises by five or six filaments from the groove between the olivary and restiform bodies. Its origin may be traced to the vesicular substance in the floor of the fourth ventricle: passing forward, it is distributed to the mucous membrane of the base of the tongue and fauces. While in the jugular fossa it forms two ganglia, a small one produced by its posterior fibres, and called the superior ganglion; a second, much larger, termed the inferior, or ganglion of Andersch. The branches given off by the glosso-pharyngeal are the muscular, the tympanic or Jacobson's nerve, which is distributed to the inner wall of the tympanum and interior portions of the ear; the pharyngeal, which supplies the pharynx, and, with branches of the pneumogastric and sympathetic, forms the pharyngeal plexus; the lingual supplies the mucous membrane of the sides and base of the tongue; the tonsillitic, which supplies the mucous membrane of the fauces and soft palate, and forms a plexus round the base of the tonsil. Besides these, the glosso-pharyngeal anastomoses with the facial, pneumogastric, accessory, and sympathetic.

Examined in the usual way, the glosso-pharyngeal proves to be a centripetal nerve, having the power of producing reflex motions through the nerves of deglutition, its motor influence being chiefly due to its connections with the pneumogastric and accessory. Though thus a sensory nerve, it is doubtful whether it be the only nerve of taste, or whether that function is not likewise participated in by the lingual branch of the fifth pair. It is certain that section of the lingual does not destroy the

sense of taste, and also that those parts of the tongue to which the glosso-pharyngeal is distributed present that sense in the most marked manner. The inference which is usually drawn is that this nerve and the lingual are both tactile and gustative, and this renders appropriate its description in this place rather than among the nerves of special sense.

ILLUSTRATION OF THE GLOSSO-PHARYNGEAL.

Fig. 168.

The glosso-pharyngeal.

Fig. 168: 1, origin of the glosso-pharyngeal between, 2, the pneumogastric, and, 3, the facial; 4, ganglion of Andersch; 5, pharyngeal branches; 6, anastomosis of the glosso-pharyngeal with the lingual branch of the facial; 7, application of the spinal to the superior ganglion of the pneumogastric; 8, branch of jugular fossa; 9, plexiform ganglion of par vagum; 10, carotid branch; 11, superior laryngeal nerve; 12, external laryngeal; 13, inferior or recurrent laryngeal; 14, cervical branch of the spinal; 15, bulbar branch of same nerve; the union of these forms a trunk which divides into two branches; 16, external branch; 17, internal branch; 18, cervical portion of sympathetic; 19, hypoglossal, cut.

DIAGRAM OF GLOSSO-PHARYNGEAL.

Fig. 169.

Diagram of anastomoses.

Fig. 169: 1, facial; 2, glosso-pharyngeal; 3, pneumogastric; 4, spinal; 5, hypoglossal; 6, superior cervical ganglion; 7, 7, anterior branches of the two first cervical pairs; 8, plexus enveloping the internal carotid artery; 9, Jacobson's nerve; 10, its anastomotic branch with the carotid plexus; 11, small deep petrosal, which passes into the great superficial petrosal; 13, otic ganglion; 14, anastomosis of glosso-pharyngeal with lingual branch of the facial; 15, anastomosis of glosso-pharyngeal and pneumogastric; 16, anastomosis of the pharyngeal of the glosso-pharyngeal with that of the pneumogastric and of the spinal; 17, auricular twig of Arnold; 18, application of the trunk of the spinal to the superior ganglion of the pneumogastric; 19, anastomosis of internal branch of the spinal with the ganglion of the trunk of the par vagum; 20, anastomosis of pneumogastric and hypoglossal; 21, anastomosis of hypoglossal with the loop formed by first and second cervical; 22, 22, anastomosis of the two first pairs with the cervical ganglion; 23, pharyngeal plexus; 24, laryngeal plexus; 25, anastomosis of the external branch of the spinal with *the anterior branch of the* third cervical pair.

OF THE TENTH PAIR, THE PAR VAGUM, OR PNEUMOGASTRIC NERVE.

The tenth pair, or pneumogastric.

The pneumogastric nerve arises by six or eight filaments from the groove between the olivary and restiform bodies below the glosso-pharyngeal, and, like it, may be traced to the vesicular material of the floor of the fourth ventricle. It first presents a small ganglion, and soon after a second, nearly an inch in length, called the plexus gangliformis. The nerve then descends the neck in the sheath of the carotid vessels, and in its course differs on the right and left sides respectively. On the right side it passes between the subclavian artery and vein, descending toward the stomach and solar plexus on the posterior portion of the œsophagus; on the left it enters the chest nearly parallel with the left subclavian, and passes to the stomach and solar plexus along the anterior portion of the œsophagus.

The chief branches of the pneumogastric are the auricular, the pharyngeal, the superior laryngeal, the cardiac, the inferior laryngeal or recurrent, the anterior pulmonary, the posterior pulmonary, the œsophageal, and the gastric.

The pneumogastric presents several plexuses in its course, and, even when distributed on the stomach, exhibits flat, membraniform ganglia. It supplies three great classes of organs: 1st. The digestive, as the pharynx, œsophagus, stomach, liver; 2d. Respiratory, as the larynx, trachea, lungs; 3d. Circulatory, as the heart and great vessels. It associates itself intimately with the sympathetic, and aids it in forming several great plexuses.

At its root the pneumogastric is sensory, but in its trunk it possesses a double function, arising from its intermingling with other nerves, as the spinal accessory and sympathetic. Though the trunk, if irritated, gives rise to pain, we are not, under ordinary circumstances, conscious of indications, as, for example, in the act of breathing, in which we do not perceive the necessity of respiration, except the access of the air be too long delayed. The pharyngeal branch is the chief motor nerve of the pharynx and palate. The superior laryngeal is the sensory nerve of the larynx, the inferior laryngeal being the motor. Considered along with the spinal accessory, the pneumogastric presents an analogy to a spinal nerve; the accessory constituting the anterior or motor root, and the pneumogastric, with its ganglion, the sensory root.

The pneumogastric nerve was formerly regarded as taking an influential part in the action of the stomach during digestion. The precise nature of its agency in this respect has been already alluded to. In addition, it may be remarked that probably through this nerve is the sensation of hunger conveyed to the mind.

ILLUSTRATION OF THE LEFT PNEUMOGASTRIC NERVE.

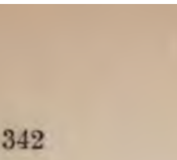
Fig. 170: 1, 1, 1, the pneumogastric nerve; 2, anastomosis of it with the hypoglossal; 3, anastomosis of plexiform ganglion with internal branch of the spinal; 4, pharyngeal, passing in front of the internal carotid artery; 5, superior laryngeal, behind the internal carotid artery; 6, external laryngeal; 7, laryngeal plexus, formed by external laryngeal and great sympathetic; 8, superior cardiac; 9, middle cardiac; 10, 10, inferior laryngeal, or recurrent, forming a curve round the arch of the aorta; 11, pulmonary ganglion; 12, its anastomosis with the great sympathetic; 13, posterior pulmonary plexus; 14, œsophageal plexus; 15, curves formed around the œsophagus by the right and left pneumogastrics; 16, œsophageal strand traversing the diaphragm; 17, plexus formed by the strand upon the anterior face of the cardiac end; 18, branches for the great end of the stomach; 19, branches for the small curvature; 20, branches for the anterior face of the stomach; 21, hepatic branches commingling with the hepatic plexus of the great sympathetic, and ramifying in the substance of the liver; 22, glosso-pharyngeal; 23, its lingual branch; 24, pharyngeal branch; 25, branch for the stylo-pharyngeal muscle; 26, spinal; 27, internal branch, aiding to form the pharyngeal nerve; 28, external branch; 29, twig of external branch anastomosing with the third cervical; 30, anastomosis with trapezian branch of the fourth cervical; 31, cervical portion of great sympathetic; 32, 32, thoracic portion; *a*, thyroid body; *b*, trachea; *c*, left lung, drawn to the right; *d*, liver, raised; *e*, œsophagus; *f*, great end of the stomach, drawn to the left; *g*, arch of the aorta; the carotid, and subclavian arteries, cut.

Fig. 170.

The left pneumogastric nerve.

ILLUSTRATION OF PULMONARY GANGLIA.

Fig. 171.

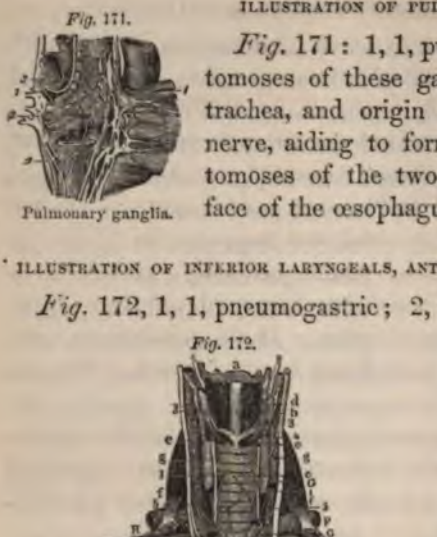


Pulmonary ganglia.

Fig. 171: 1, 1, pulmonary ganglia; 2, median anastomoses of these ganglia at the posterior face of the trachea, and origin of the bronchi; 3, left laryngeal nerve, aiding to form the bronchial plexus; 4, anastomoses of the two pneumogastrics on the posterior face of the œsophagus.

ILLUSTRATION OF INFERIOR LARYNGEALS, ANTERIOR PULMONARY, AND CARDIAC PLEXUS.

Fig. 172.



The inferior laryngeals.

Fig. 172, 1, 1, pneumogastric; 2, 2, superior laryngeal; 3, 3, external laryngeal; 4, superior cardiac nerve; 5, 5, middle cardiac nerves; 6, inferior cardiacs; 7, cardiac ganglion and plexus; 8, 8, nerves from this plexus surrounding the coronary plexus; 9, 9, anterior pulmonary plexus; 10, 10, inferior laryngeal: the left embracing the arch of the aorta, the right the subclavian artery, both go to the posterior face of the larynx; 11, tracheal branches; A, pulmonary artery; B, its left branch; C, its right branch; D, arch of the aorta; E, fibrous cord arising from obliteration of the ductus arteriosus; F, left subclavian; G, G, left primitive carotid; H, brachio-cephalic trunk, cut to show cardiac nerves; I, vena cava superior; K, left coronary artery and vein; L, right coronary artery and vein, *a*, os hyoides; *b*, projecting portion of the larynx; *c*, trachea; *d*, thyro-hyoid muscle; *e*, *e*, crico-thyroid; *f*, *f*, scalenus anticus; *g*, *g*, thyroid body; *h*, *h*, diaphragm; *i*, *i*, pericardium, cut away.

OF THE ELEVENTH PAIR, OR SPINAL ACCESSORY NERVE.

The eleventh pair, or spinal accessory.

The spinal accessory arises by several filaments from the side of the spinal cord, as low as the fifth or sixth cervical nerve. In its upward course it communicates with the posterior roots of the first cervical. It then divides into two branches, the smaller joining the pneumogastric, the main trunk passing onward, and being eventually distributed to the trapezius muscle, and also furnishing supplies to the sterno-mastoid.

The spinal accessory is a motor nerve, as appears from the usual evi-

dence of irritation, and also from its origin and distribution. Its action is not essential in ordinary or involuntary respiration. In voluntary respiration it is brought into play.

OF THE TWELFTH PAIR, OR HYPOGLOSSAL NERVE.

This nerve arises in the groove between the pyramidal and olivary bodies, by 8 or 10 filaments, which are collected into two bundles. It next passes forward and crosses inward, pursues a course which is concave upward, and supplies the genio-hyoglossus and muscles of the tongue generally, giving off the following branches in its course: the descendens noni, the thyro-hyoid, and filaments connecting the gustative nerve. It also anastomoses with the pneumogastric, spinal accessory, first and second cervical nerves, and sympathetic.

The twelfth pair, or hypoglossal.

The hypoglossal is the motor nerve of the tongue, irritation of it giving rise to movements throughout that organ, the lingual branch of the fifth being the sensory. The hypoglossal causes the muscles of the neck to aid in the movements necessary for articulate speech.

ILLUSTRATION OF THE HYPOGLOSSAL NERVE.

Fig. 173: 1, medulla oblongata; 2, glosso-pharyngeal; 3, pneumogastric; 4, superior laryngeal; 5, spinal; 6, first cervical pair; 7, second pair; 8, third pair; 9, fourth pair; 10, lingual; 11, origin of hypoglossal; 12, anastomosis of hypoglossal with first cervical; 13, anastomosis with nervous loop of two first cervicals; 14, descending branch of hypoglossal, anastomosing with, 15, descending branches of cervical plexus; 16, twig of thyro-hyoid muscle; 17, branches of hyoglossus; 18, recurrent branch of stylo-glossus; 19, branches of genio-hyoid; 20, plexiform branches of hypoglossal; 21, anastomotic branch with the lingual; 22, branch for submaxillary ganglion; A, vertebral artery; B, external carotid; C, lingual; D, temporal; E, internal maxillary; *a*, portion of the condyle of the occipital bone; *b*, median section of atlas; *c*, styloid process; *d*, stylo-glossus; *e*, stylo-pharyngeus; *f*, hyoglossus; *g*, genioglossus; *h*, pterygoideus externus; *i*, pterygoideus internus.

Fig. 173.

The hypoglossal nerve.

OF THE PHRENIC NERVE.

Although the phrenic, or internal respiratory nerve is not strictly in-

The phrenic nerve. cluded in the group now under consideration, yet, considering its important connection with the motions of respiration, it is proper to describe and illustrate it here.

It arises from the third and fourth cervical nerves, aided by a branch from the fifth, or from the brachial plexus, and from the sympathetic. In its descent it communicates with the lower cervical ganglion, enters the thorax between the subclavian vein and artery, and, passing along the side of the pericardium, descends to the diaphragm, the right phrenic being perpendicular, and the left running obliquely round the apex of the heart. It is distributed, for the most part, to both faces of the diaphragm, superior and inferior. It is the motor nerve of the diaphragm.

Fig. 174.

The phrenic nerve.

ILLUSTRATION OF THE PHRENIC NERVE.

Fig. 174: 1, 1, root of the phrenic nerve, furnished by the fourth cervical; 2, 2, roots from the brachial plexus; anastomosis of this nerve with branch of the subclavian; 4, anastomosis with the inferior cervical ganglion; 5, 5, curve of the hypoglossal, cut, sending a twig to the phrenic nerve; 6, 6, pericardiac branches of the phrenic nerve; 7, 7, branches to the superior face of the diaphragm; 8, 8, branches to the inferior face of the diaphragm; 9, anastomoses of these branches with, 10, the solar plexus; 11, transverse communication of the phrenic nerves.

OF THE GREAT SYMPATHETIC NERVE.

Under the designations of sympathetic, visceral, trisplanchnic, gangli-onic, intercostal, or nerve of organic life, passes a series of reddish or gray ganglia, interconnected by nervous strands, extending along each side of the vertebral column, from the head to the coccyx, communicating with all other nerves of the body, and distributing branches to the internal viscera, or organs of involuntary function. These ganglia are less numerous than the vertebræ; the chain on each side communicates with its colleague through plexuses, and the ganglion impar is the common uniting point on the coccyx below. By some it is supposed that the ganglion of Ribes, and by others that the pituitary body has the same function in the cranium above.

Position and structure of the sympathetic.

are here spoken of as nervous strands are perhaps more correctly gations of the ganglia themselves.

origin of the sympathetic has been long a subject of dispute, some sing that it is a special system, of which the ganglia are ny independent centres, establishing incidental commu- ns with the cerebro-spinal; others, that its origin is in the internal a, and its termination in the cerebro-spinal system, this opinion be- pported by the alleged facts that the sympathetic, in its develop- appears before the other parts of the nervous system, and simulta- ly with the splanchnic organs, and that it has been found in mon- without a brain or spinal cord; others, again, suppose that it orig- from the roots of the cerebro-spinal system, and terminates in the r organs. Regarding it in this light, some have imputed its origin the spinal, and fifth and sixth cranial conjointly; others have lim- to the two latter.

Origin of the sympathetic.

pneumogastric nerve aids it in forming three of its plexuses, the ngeal, cardiac, and solar. In certain respects the pneu- tric and sympathetic seem to exhibit a reciprocal de- nent, in some of the lower animals the former pre- ating over, and supplying the place of the latter; and this replace- it is said, goes on in the descending series until, in the cephalopo- mollusks, the sympathetic has disappeared, and the pneumogastric its place.

Relations of pneumogastric and sympathetic.

Fig. 175.

lation of the sympathetic and spinal.

Fig. 175 illustrates the relation of the sympathetic and spinal nerves: *c*, *c*, anterior fissure of the spinal cord; *a*, anterior root of a dorsal spinal nerve; *p*, posterior root, with its ganglion; *a′*, anterior branch; *p′*, posterior branch; *s*, sympathetic; *e*, its double junction with the anterior branch of the spinal nerve by a white and a gray filament.

The sympathetic chain therefore establishes connections with the cerebro-spinal system. Each spinal nerve is brought into relation with it through two strands, a tubular or white, and a gelatinous or gray. The tubular or white strand may be regarded as actually arising from the spinal cord, and consisting of motor and sensory filaments. It makes its

Connection of sympathetic and spinal system.

way to the ganglion of the sympathetic, passes over and through it, its fibres conjoining themselves with gray ones, which they have gathered in the ganglion. The gray or gelatinous root is to be viewed as having its origin in the ganglion of the sympathetic, and sending its fibres chiefly to the ganglion on the posterior root of the spinal nerve, but few of them doubtfully communicating with the anterior root. The fibres which seem to enter the cord are probably for the supply of blood-vessels. Each of these sympathetic ganglia is, therefore, a nervous centre, sending forth strands in three directions: 1st. To join the spinal fibres in their distribution; 2d. To the spinal cord itself, or chiefly to the ganglia on the posterior roots of its nerves; 3d. To the next sympathetic ganglion above.

Sympathetic plexuses.

In the various plexuses of the sympathetic, vesicles are found, from which gray fibres seem to originate. The branches which supply the viscera constantly form plexuses; the arteries are surrounded with such a net-work. The splanchnic ganglia, with their interconnecting strands, and supplies from the cerebro-spinal, give rise to four great plexuses: the pharyngeal, the cardiac, the solar, and the hypogastric. The first and last of these are in symmetrical pairs; the other two are single, and placed on the median line.

Physical effects of sympathetic ganglia.

From its construction the sympathetic can not be regarded as an isolated or self-acting system, since all its branches contain fibres derived from the cerebro-spinal. In function it must therefore be adjuvant to that system, and it must be admitted that the motor and sensory qualities of the included spinal fibres, according as they have been derived from the anterior or posterior columns of the cord, are continued in their association with the sympathetic. Hence, in so far as being a compound nerve, it possesses both those functions, and this conclusion is corroborated by such facts as those of the distribution of the sympathetic both to muscular portions, as to the heart, and also to sensitive ones; by the circumstance that the intestinal canal from the stomach to the end of the colon receives its nervous supply from this source alone. Experiments on the sympathetic ganglia establish a similar conclusion, irritation of the cœliac ganglion, for instance, giving rise to increased peristaltic motions, and pathological observations furnishing like evidence as regards the sensory function. Compared with other nerve trunks, the sympathetic is much less active in these respects, a high irritation of the parts supplied by it often being required to cause pain, and, in like manner, its motor fibres are little under the influence of the will.

The sympathetic transmits sensations so tardily that it has been supposed that one office of its ganglia is for the purpose of cutting off such impressions; and, in like manner, when motor fibres of the cerebro-spinal system pass through its ganglia, their conducting power appears to

be impaired. There does not seem to be any decisive proof that any of the fibres of the sympathetic, properly speaking, are motor or sensory, or that its ganglia produce reflex action, the agency which it exerts in these respects on the muscular structure of the heart, blood-vessels, digestive or urinary organs, being due to the associated cerebro-spinal fibres.

In this manner, by its distribution to the arteries, the sympathetic, as a compound nerve, exerts a power over the passage of the blood through them by influencing their contractility, and thereby their diameter. In virtue of this, it therefore affects the rapidity of secretion, and also regulates the rate of nutrition. The entire digestive tract, with its dependencies are thus brought under its influence, the salivary glands, pharynx, œsophagus, stomach, intestine, nasal, bronchial, and pulmonary surfaces, etc.

Its ganglia are reservoirs of force.

The view of the function of ganglia presented on preceding pages is strongly supported by the mechanism and phenomena of the sympathetic nerve. Its ganglia permit the influence passing along the nervous cords to escape therefrom into new channels, and also retain and store up nervous power. They become, therefore, magazines of force, and are hence capable of sustaining rhythmic movements. Even after organs have been exsected, they will still exhibit, under the influence of these ganglia, their accustomed motion, as is the case with the heart, which, in some of the cold-blooded animals, will continue its contractions for many hours after it has been cut out of the body.

Conclusion respecting the functions of the sympathetic.

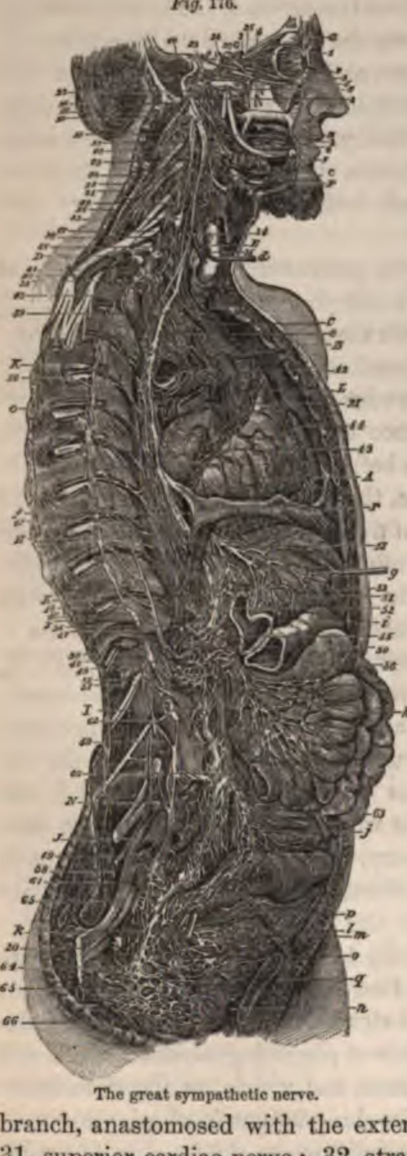
I therefore regard the sympathetic system as having for one of its main functions the equalization or balancing of the nervous force, storing up all transient excesses of it, and furnishing all transient deficiencies. As in a mechanical contrivance, in which the prime mover works in an irregular way, the fly-wheel harmonizes all such variations, storing up or supplying power as the circumstances may require, so does this complicated apparatus act in the mechanism of innervation. And it is worthy of remark, that some such arrangement would seem to be necessary, since the organs of digestion, to which the sympathetic is so largely directed, are periodically in activity and periodically quiescent.

It is to be greatly regretted that the term sympathetic has been applied to this important nerve, since that term, as defining function, has led to the promulgation of theoretical views which have exerted an influence to the disadvantage of the progress of physiology—views which will not bear the test of anatomical criticism, and which are therefore incorrect. It is always much better to give designations in allusion to structure or position than to function, especially where the function is doubtful. For this reason, the title of intercostal is much preferable to that of nerve of organic life, and trisplanchnic better than sympathetic—an

imposing but mysterious epithet, which has been a source of injury to the science, and which it would be well even now to replace by such a term as vincular or moniliform nerve, or some title of equivalent import.

ILLUSTRATION OF THE GREAT SYMPATHETIC.

Fig. 176.



The great sympathetic nerve.

Fig. 176: 1, globe of the eye, dissected so as to show the ciliary nerves; 2, branch of the inferior oblique and the motor root of the ophthalmic ganglion; 3, 3, 3, the three branches of the trifacial, in connection with most of the cranial ganglia, that is, with, 4, ophthalmic ganglion, 5, spheno-palatine, 6, otic, 7, submaxillary, and, 8, sublingual; 9, external motor oculi; 10, facial and its anastomoses with the spheno-palatine and otic ganglia; 11, glosso-pharyngeal; 12, 12, right pneumogastric; 13, left pneumogastric; 14, spinal; 15, hypoglossal; 16, 16, cervical plexus; 17, brachial plexus; 18, 18, intercostal nerves; 19, 19, lumbar plexus; 20, sacral plexus; 21, superior cervical ganglion, furnishing two carotid branches, forming the carotid plexus around the artery of that name, and from which arise the anastomoses with, 22, nerve of Jacobson, 23, carotid branch of vidian nerve, 24, external motor oculi, 25, ophthalmic ganglion; 26, twig for the pituitary gland; 27, anastomosis of superior cervical ganglion with the first cervical pairs; 28, carotid and pharyngeal branches; 29, pharyngeal and intercarotid plexus; 30, laryngeal branch, anastomosed with the external laryngeal of the pneumogastric; 31, superior cardiac nerve; 32, strands of junction of the superior cervical ganglion with, 33, middle cervical ganglion: among the internal *branches of* the latter are, 34, the anastomotic with, 35, the recurrent

, 36, middle cardiac nerve; 37, strand of junction of middle cervical lion with, 38, inferior cervical ganglion; 40, twigs furnished by in- cervical ganglion around the subclavian and vertebral arteries; 41, omotic branch with the first intercostal nerve; 42, cardiac plexus ganglion; 43, 44, secondary plexuses of right and left coronary ar- s; from 45 to 46, thoracic ganglionary chain; 47, the great splanch- raversing the diaphragm, and going to, 48, semilunar ganglion; 49, splanchnic; 50, solar plexus, receiving, 51, anastomosis of pneu- stric, 52, phrenic nerve; 53, gastric coronary; 54, hepatic; 55, sple- 56, superior mesenteric, enveloping the arteries of those names; 57, plexus; from 58 to 58, lumbar ganglionic chain; 59, lumbo-aortic is, presenting two enlargements, one, 60, above, the other, 61, below ifurcation of the aorta; 62, spermatic plexus; 63, inferior mesenteric; ypogastric plexus; 65 to 65, sacral ganglionic chain; 66, terminal geal ganglion; A, heart, slightly turned aside to show the cardiac is; B, arch of the aorta, also drawn aside by hook; C, innominata; ibclavian, cut, to show inferior cervical ganglion; E, inferior thy- F, portion of external carotid; G, internal carotid; H, thoracic ; I, abdominal aorta; J, primitive iliac; K, intercostals; L, pul- iry artery, of which the right branch is cut; M, superior vena cava, t its origin; N, vena cava inferior; O, pulmonary veins; *a*, lach- l gland; *b*, sublingual gland; *c*, submaxillary gland; *d*, thyroid ; *e*, trachea; *f*, œsophagus, going to, *g*, the stomach; *h*, several in- ial loops with superior mesenteric plexus; *i*, transverse colon; *j*, oid flexure; *k*, rectum; *l*, bladder; *m*, ureter; *n*, prostate; *o*, vesicula seminalis; *p*, vas deferens; *q*, spermatic cord; *r*, *r*, diaphragm.

Fig. 177.

The abdominal plexuses.

THE ABDOMINAL PLEXUSES.

Fig. 177: 1, 1, 1, 1, portion of the right and left ganglionic chain; 2, coccygeal ganglion; 3, median anastomoses of the two sacral cords; 4, 4, great splanchnic, right and left, traversing the diaphragm, and going to, 5, 5, semilunar ganglia; 6, solar plexus; 7, splenic plexus; 8, hepatic plexus; 9, coronary plexus of stomach; 10, anastomoses of the two pneumogastrics, right and left, with solar plexus and gastric coronary; 11, diaphragmatic plexus and superior capsular; 12, anastomoses of these two plexuses with the phrenic nerve; 13, middle capsular plexus; 14, inferior capsu-

lar plexus, coming from, 15, renal plexus; 16, 16, lesser splanchnics, traversing the diaphragm; 17, superior mesenteric plexus; 18, spermatic plexus, arising from three sources, the renal, lumbo-aortic, and hypogastric; from 19 to 19, lumbo-aortic plexus; 20, 20, its bifurcations; 21, inferior mesenteric plexus; 22, 22, its anastomoses with, 23, 23, hypogastric plexus on each side; 24, 24, sacral plexus; *a*, diaphragm, cut; *b*, portion of stomach and œsophagus; *c*, spleen; *d*, kidney and its supra-renal capsule; *e*, testicle; *f*, ureter, cut; A, A, aorta.

THE SOLAR PLEXUS.

Fig. 178: 1, solar plexus, furnishing, 2, hepatic plexus; 3, gastric coronary plexus, and, 4, splenic plexus; 5, anastomoses of right and left pneumogastric with the solar plexus and gastric coronary; 6, branches of pneumogastric going to the liver; 7, plexus of biliary ducts; 8, origin of superior mesenteric plexus; 9, renal plexus; 10, capsular plexus; 11, 11, spermatic plexus; 12, commencement of lumbo-aortic plexus; 13, portion of inferior mesenteric plexus; *a*, the liver, raised; *b*, the stomach, cut at its great end; *c*, the spleen; *d*, the kidney; *e*, kidney, cut; *f*, supra-renal capsule; *g*, *g*, ureters; *h*, duodenum; *i*, *i*, pancreas.

Fig. 178.

The solar plexus.

Fig. 179.

The mesenteric plexuses.

SUPERIOR MESENTERIC AND INFERIOR MESENTERIC PLEXUS.

Fig. 179: 1, superior mesenteric plexus, surrounding the divisions of the artery of the same name, and offering many flat ganglia; 2, portion of inferior mesenteric plexus; *a*, cœcum and appendix vermiformis; *b*, *b*, transverse colon; *c*, portion of small intestine.

CHAPTER XVIII.

OF THE VOICE.

Origin of the Voice.—Comparative Physiology of Noise, Song, Voice.—Distinction between Song and Speech.—The Larynx, and its Action in Singing.—Müller's Explanation of the Action of the Vocal Organs.—Speaking Animals and Machines.

Nature of Words and their constituent Sounds.—Vowels and Consonants.—Whispering.—Use of the Voice of Animals.

Of Languages: their Duration, Character, History.—Registry of Sounds by Writing and Printing.—Musical Signs.—Alphabetic Writing.

For the production of the sounds necessary for intercommunication among the higher animals, and particularly for the speech of man, it might be supposed that some complicated and elaborate contrivance must needs be resorted to. This object is, however, accomplished by merely employing, on its escape from the system, the wasted product of respiration, the breath, which, as it issues outward through the respiratory passages, sets in motion a simple mechanism, and thereby originates all the exquisite modulations of song, and all the impressive utterances of speech. Is it not to be admired that thus, out of dead and dismissed matter, results of so high an order, materially and mentally, are obtained?

Voice arises from wasted products of respiration.

What might be termed the comparative physiology of the voice is very simple. It appears first in invertebrate animals as a monotonous noise or cry, which gradually, in higher tribes, becomes more varied in loudness and note. It is worthy of remark that, in the different stages of his existence man himself furnishes an illustration of this course. Voiceless before birth, with a piteous or monotonous cry in early infancy, articulate speech and song are the result of education, and through these the power is eventually gained of expressing the most refined emotions and the most elevated ideas. The solitary bell-like sound which the nudibranchiate gasteropods emit, thus produces, by its successive improvements, a wonderful result at last.

Comparative physiology of the voice.

Among insects the modes of producing sounds are very various, some effecting it by percussion, some by the friction of horny organs. In others, the extremity of the trachea, through which the air escapes, is accommodated with vibrating membranes. According to Burmeister, the contractions of the muscles of the wings, which are brought vigorously into action during flying, occasion

Production of rudimentary sounds.

Fig. 180.

Spiracle of insect.

an alternate pressure and relaxation upon the tracheal tubes. The air, thus passing in and out, throws into vibration the valves of the spiracle, which, as seen in *Fig.* 180, are suspended upon a dozen or more flexible supports; but their free edges, approaching within a certain distance of each other, are thrown into quick vibration by the passing current, in the same manner as is the vibrating spring of the accordeon. These vibrating plates of insects are the rudiments of what will become the perfect vocal apparatus in man. Again, in others, the swiftly-recurring beating of the wings produces a sound, as, for example, in the musquito. Among vertebrated animals, those which breathe the air are vocal, nearly all fishes being mute. From fishes, as we pass upward, the sound and the instrument which makes it increase together in complexity. Through a simple chink, the air expelled from the respiratory sacs of snakes, by the contraction of their abdominal muscles, issues forth as a mere hiss, the sound being increased in the frog by the development of resonant cavities. From these simple noises we are conducted to the musical notes of birds, some of which are of exquisite purity and sweetness. In these, the vocal glottis is situated at the bifurcation of the trachea, another glottis being above for the final escape of the air. These vertebrated animals first introduce us to the mechanism for articulate speech, the raven and parrot being able to pronounce words with distinctness. The articulation is effected, as in man, by the motions of the tongue and other portions of the mouth.

Sounds of reptiles and birds.

Talking birds.

For the further consideration of this subject, it is necessary to understand that there is a distinction between song and speech. Song is produced by the glottis, speech by the mouth; or, perhaps, a more correct statement would be, that the larynx is the organ of song, the mouth of that form of speech which we call whispering, and for which nothing is required but a stream of air issuing from the fauces, the tongue and other organs giving it articulation; but for audible speech, a noise is created in the larynx, and modified by articulation in the mouth.

Distinction between song and speech.

The double larynx of birds is replaced by a single larynx in man, which serves at the same time for the entrance and exit of air, and likewise for vocalization. Those birds in which the lower larynx is absent are voiceless. A general idea of the construction of the organ of voice

in man may be gathered by supposing it to be composed of three portions, the trachea, the larynx, and the mouth. The trachea is the tube by which air is brought from the lungs and delivered into the larynx, which is a superposed structure, arranged upon the cricoid cartilage, on which is articulated the thyroid cartilage by its lower horns, around which a certain degree of rotation can be accomplished, so that the front of the thyroid may be elevated or depressed with a kind of bowing motion. Posteriorly, on the cricoid cartilage are placed the arytenoid cartilages, which can be approached or separated from each other, and from their summits pass to the front of the thyroid cartilage the inferior laryngeal ligaments or vocal cords. These constitute the essential organ of sound. The thyroid cartilage, by its motions, can determine the strain put upon them, and the arytenoids can either bring them into parallelism, or place them at an acute angle. The chink or fissure between them is the rima glottidis: its figure and width vary with the recession or approximation of the vocal cords, which, as the air passes by them, are thrown into vibration in the same manner as the reed in musical instruments. The epiglottis cartilage, which is above, guards the passage, and may also be supposed, by its descent, to deaden the sounds.

Description of the larynx.

The slowness or rapidity of the vibration is dependent on the stretch of the vocal cords. The manner in which various degrees of tension can be given to the cords is readily understood by considering their attachments. In front, as we have said, they are fastened to the thyroid cartilage, posteriorly to the arytenoids. When the thyroid cartilage executes a bowing motion forward, the vocal cords are put upon the stretch, and similar variations of their tension and also of their position can be given by the movements of the arytenoid cartilages behind. When the air is moving in and out without giving rise to any sound, the chink of the glottis is angular, its point being forward, and from that the cords diverge posteriorly. For the production of sound, the cords must be brought parallel, or even inclining toward each other. If they incline away from each other, no sound will be produced. The pitch of the note will be determined by the stretch of the cords, and this, in its turn, will be determined by the contraction of the vocal muscles. The crico-thyroid and sterno-thyroid bow the front of the thyroid cartilage down, the thyro-arytenoid and thyro-hyoid carry it back; the former therefore stretch the cords, and the latter relax them. The opening of the glottis is likewise determined by other muscles, the posterior crico-arytenoid dilating it, and the lateral crico-arytenoid and the transverse arytenoid closing it.

Regulation of the vocal cords.

Fig. 181, p. 354, is the larynx, seen in profile: *a*, *a*, half of the hyoid bone; *b*, thyroid cartilage, cut; *c*, thyro-hyoid membrane; *d*, cricoid cartilage; *e*, trachea; *f*, œsophagus; *g*, epiglottis; *h*, great horn of the

Fig. 181.

Profile of larynx.

thyroid cartilage, united to, *i*, the great horn of the os hyoides by, *k*, the lateral thyro-hyoid ligament; *l*, thyro-hyoid membrane, traversed by the superior laryngeal nerve; *m*, posterior crico-arytenoid muscle; *n*, lateral crico-arytenoid; 1, inferior laryngeal nerve; 2, posterior crico-arytenoid twigs; 3, lateral crico-arytenoid twigs; 4, thyro-arytenoid twigs; 5, arytenoid twig.

Fig. 182.

Posterior view of larynx.

Fig. 182 is the posterior view of the larynx: *a*, base of the tongue; *b*, posterior border of the thyroid cartilage; *c*, *c*, thyroid body; *d*, posterior crico-arytenoid muscle; *e*, arytenoid muscle; 1, 1, superior laryngeal, traversing the superior thyro-hyoid membrane, and giving off lingual and epiglottic branches, and others to the mucous membrane covering the posterior face of the larynx; 2, twig for the arytenoid muscle; 3, anastomotic of Galien; 4, inferior laryngeal; 5, tracheal branches; 6, twig for the posterior crico-arytenoid muscle; 7, twig for the arytenoid muscle; 8, branch for the lateral crico-arytenoid and posterior crico-arytenoid muscles.

Müller's explanation of the action of the vocal organs.

The researches of Müller furnish the best account we possess of the action of the vocal organs. He has shown that the larynx is essentially a reed instrument with a double membranous tongue. That the rima glottidis is the seat of the origin of the sound is proved by the fact that when an aperture exists in the trachea below the glottis the voice disappears, but if above the glottis there is no effect. Magendie records the case of a man who had a fistulous opening in his trachea, and who could not speak unless he closed it or wore a tight cravat. Moreover, the human or animal larynx can be made to produce its characteristic sounds with more or less distinctness, after it has been removed from the body, by directing a current of air through the trachea. Cases have occurred which have afforded the opportunity of observing the condition of the glottis while emitting sounds. The vocal cords are brought into parallelism with one another, and separated by an interval of scarcely more than from the $\frac{1}{100}$ to the $\frac{1}{150}$ of an inch; but when the air is moving in and out silently, the fissure assumes a divergent or triangular form.

Professor Müller gives the following account of the mode of production of the notes of the natural voice. "The vocal ligaments vibrate in their entire length, and with them the surrounding membranes and the thyro-arytenoid muscles. For the deepest notes, the vocal ligaments are much relaxed by the approximation of the thyroid to the arytenoid cartilages. The lips of the glottis are, in this state of the larynx, not only *quite* devoid of tension; they are, when at rest, even wrinkled and pli-

cated, but they become stretched by the current of air, and thus acquire the degree of tension necessary for vibration. From the deepest note thus produced, the vocal sounds may be raised about an octave by allowing the vocal cords to have a slight degree of tension, which the elastic crico-thyroid ligament can give them by drawing the thyroid cartilage toward the cricoid. The medium state, in which the cords are neither relaxed and wrinkled nor stretched, is the condition for the middle notes of the natural register, those which are most easily produced. The ordinary tones of the voice in speaking are intermediate between these and the deep bass notes. The higher notes are produced and the corresponding falsetto notes avoided by the lateral compression of the vocal cords, and by the narrowing of the space beneath them by means of the thyro-arytenoid muscles, and farther by increasing the force of the current of air; the muscular tension given to the lips of the glottis by the muscles above mentioned must also be taken into account, as contributing to the production of the notes of the natural register."

Artificial larynx.

An artificial larynx, constructed in such a way as to represent more or less perfectly the preceding conditions, will give rise to sounds analogous to those of the human larynx. Such have been made of leather, and, better still, of caoutchouc.

Relations of the larynx in singing.

The narrower the glottis is made, and the more tightly the cords are strained, the more rapidly they will vibrate, and the higher will be the musical note emitted. In an individual the range of the voice is rarely three octaves, but the male and female voice, taken together, may be considered as reaching to four. Generally, the lowest female note is about an octave higher than the lowest male, a similar remark applying to their highest notes respectively. They differ also intrinsically from each other, just as different wind instruments sounding the same note give it of a different quality. Moreover, in each sex there are different voices: in the male, the base and the tenor; in the female, the contralto and soprano. The base usually reaches lower notes than the tenor, and the tenor higher than the base; the contralto reaches usually lower notes than the soprano, and the soprano higher ones than the contralto, though these distinctions are by no means uniform. There are, again, intermediate complications: thus the barytone intervenes between the base and the tenor, and the mezzo soprano between the contralto and soprano. The chief reason for the difference between the voice in the sexes is in the difference of the length of their vocal cords, which are in men and women respectively in the proportion of three to two; but besides this, those personal peculiarities which we so readily recognize in the voices of individuals are due to differences in the structure of the tissues forming the vocal mechanism, or peculiarities in the size and condition of the resonant cavities. Frequently the same

individual is capable of singing in two different voices, known as chest notes and falsetto notes. The chest notes are produced by the ordinary mode of vibration; the falsetto notes, which are purer or more fluty, are considered to be probably due to vibrations of the harmonic subdivisions of the column of air in the trachea, or to vibrations of the inner borders of the vocal cords.

Speaking animals and machines.

While thus song is laryngeal, speech, which is a modification thereof, is oral, or produced by the mouth. Man is not alone endowed with the faculty of uttering articulate sounds: there are several other animals which, by education, may be taught to express them. Ingenious mechanics have also repeatedly invented instruments, the construction of which, being upon the same principle as that of the vocal organs, has combined the sounds of letters into words, and even into sentences, a convincing proof not only of the mechanical nature of articulate sounds, but also of the perfect manner in which the natural mechanism is understood. Animals which have been taught to speak may also be regarded as automata, for they have no comprehension of what it is they are uttering, and never produce articulate combinations spontaneously, but only as the result of instruction.

Words originate by combining their letters.

Like the automata just alluded to, the human voice expresses words by combining their constituent letters together. Grammarians divide letters into two groups, vowels and consonants, defining the vowel as a sound that can be uttered by itself, the consonant taking its name from the fact that it can only be uttered consonantly with a vowel. By personal experiment, it may be easily proved that the vowel is a continuous sound, which may be kept up just as long as the breath will enable, and, on examining the position of the tongue and other movable portions of the mouth, the particular arrangement necessary for pronouncing the letters *a*, *e*, *i*, *o*, *u*, or the sixteen or eighteen vowel sounds of the Continental languages, will be detected. It will be found that the determining condition is, for the most part, the peculiar modification of the oral apertures. It will also be discovered that articulation is wholly independent of the larynx, since merely by expelling the air through the mouth, without permitting any laryngeal sound to be formed, all the letters may be articulated in a whisper. M. Deleau has illustrated this fact in an ingenious way by putting an India-rubber tube through the nostril, so as to reach the posterior portion of the mouth, and causing another individual to blow gently through it; while the organs of the mouth are silently thrown into those positions necessary for the utterance of any particular sound, that articulate sound will at once appear in whispers; but if, while this is being done, the larynx is permitted to yield a sound, two voices then are heard, one in audible speech and one in a whisper, the

Consonants and vowels.

Nature of whispering.

former belonging to the individual who is making the experiment, and the other arising from the air which his companion is blowing into the tube. There is no kind of difficulty in constructing a simple kind of instrument from which the sounds of the vowels can be produced by gently blowing air into it.

Explosive and continuous consonants.

The consonants are of two kinds, the explosive and continuous. The former arise from an abrupt and momentary action, and disappear at once; as examples of these, the letters *b*, *d*, *p*, in which it may be remarked that the characteristic of the sound disappears in an instant; hence the term explosive; and if any attempt be made to continue it, it issues in the utterance of the vowel *e*; but in the continuous consonants this does not take place, as in the letters *n*, *f*, *s*. In the case of the consonants, as in that of the vowels, the peculiar arrangement of the parts of the mouth, though difficult to describe, may be readily ascertained by personal experiment.

Use of the voice of animals.

Of vocal sounds thus originating, it may be remarked, that in the lower tribes of animals, their chief use seems to have reference to the perpetuation of the race. Even in the highest, the changes of the reproductive and vocal organs often occur contemporaneously; but, though this may be true of mere sounds, the modulated variations thereof have a far more general use. Of languages it may be said that they are the creation of groups or nations of men, not of individuals, and hence they reach beyond the compass of individual life, in some instances having endured for thousands of years. Moreover, if critically considered, each often contains the history of the race by which it is spoken, and even manifests the broader features of its character; so our own tongue contains the indications of the two chief political events which have befallen the English nation, at least so far as foreign relations are concerned—the conquest of Britain by the Romans, and, a thousand years after, by the French. In consequence of the first of these events, the language became, so far as common expressions are concerned, almost bi-lingual. Such simple illustrations as the words God, deity; fatherly, paternal; motherly, maternal; heavenly, celestial; earthly, terrestrial; hellish, infernal; womanly, feminine, may serve as examples. So well recognized are these principles among linguists that they are resorted to for the decision of pre-historical questions. The best and most precise evidence that we have of the Indian origin of the German nations is derived from the occurrence of Sanscrit roots in their vocabulary, and analogies in their grammar. The names of many domestic animals, of farming implements, and of many common objects, are the same in Sanscrit, Latin, Greek, and German.

Of languages: their duration.

Nay, even more than this, from the structure of a language, collated with the history of the people by which it is spoken, we can often judge

Connection of language with national peculiarities and history.

of the influence of events more perfectly than in any other way; so in the two instances which we are referring to as illustrations of these remarks, the French conquest did not make that deep and abiding impression which the Roman one had done. A thousand years had elapsed between the invasion of Cæsar and that of William of Normandy, eight hundred only from the latter event to our times, yet the influence of the masculine and civilizing Roman has reached through that long interval, has made the deepest impression on the national character, and is manifested in almost one half of the sentences that we utter.

Registry of sounds by writing and printing.

Connected with articulate speech, it may not be out of place to allude briefly to those great advances which have been made by the genius of man in the permanent record or registering by written signs; and as sounds are of two kinds, musical and articulate, so we have two distinct methods of writing; and this, leaving out all the earlier and more imperfect forms, a method for music and one for speech. Of the former, it is scarcely necessary to remark that it is universal; the combination of sounds designed to be conveyed is comprehended at once by men of every nation; but in the writing for speech, various methods have been employed at different times and by different nations, from mere picture writing, each sign of which called forth in different languages different sounds, through the hieroglyphic and Chinese methods up to that most splendid invention of later ages, alphabetic writing, the principle of which is absolutely perfect, because it is natural, being to decompose each word into each constituent vowel or consonant sound which it contains, and to write a mark or letter representing each of those sounds. Though many circumstances have contributed to the advancement of the human race, it can not be doubted that this invention has exceeded all others in power, and that alphabetic writing has been the great instrument of civilization.

Different methods of expressing language.

CHAPTER XIX.

OF HEARING.

he Senses: General Remarks upon.—Five Organs of Sense.—Necessity of Apparatus for the Appreciation of Time, Space, Pressure, Temperature, and Chemical Qualities.
Hearing.—General Structure of the Organ of Hearing.—Physical Peculiarities of Sounds, Intensity, Time of Vibration, and Quality.—The Tympanum, Cochlea, and Semicircular Canals are for the Appreciation of these peculiarities.
ructure and Functions of the Tympanum, or Measurement of Intensity.
ructure of the Cochlea, its Spiral Lamina and Scalæ.—Measures the Time of Vibration.—Accomplishment of Interference in the Scalæ.—Comparative Anatomy of the Cochlea.
ructure of the Semicircular Canals.—They estimate the Quality of Sounds.
mparative Anatomy of the Auditory Mechanism.—Its Progress in Development.—Imperfection of the Doctrine of Means and Ends.

OF THE SENSES.

THE organs and functions which have thus far been described have ference, for the most part, to the conservation of the indi- dual being, maintaining its structure unimpaired, notwith- anding the waste it is perpetually undergoing, or conducting its devel- ment. We now enter on the consideration of a totally distinct ap- aratus, the object of which is to put the individual in relation with ex- rnal nature, and to which, therefore, the designation of mechanism of cternal relation may be appropriately given. Function of the senses.

For the sentient being in its highest development, means must be pro- ded for the perception of time, space, force, and quality. his is accomplished by what are termed the organs of sense. hey are five in number: 1st. The organ of hearing; 2d. That of see- g; 3d. That of touching; 4th. That of smelling; 5th. That of tasting. a the further description of the senses, it will be found that the ear is e organ of time; the eye that of space; the tactile apparatus is for the erception of force; and that the mechanism for smelling and tasting con- intly determine the chemical qualities of bodies; that of smelling ad- essing itself to substances which are in the vaporous and gaseous state; d that of tasting, to such as are liquid or dissolved in water. Five organs of sense.

We shall pursue the description of the senses in the order in which ey have been just enumerated, premising of them respect- ely that, the function of hearing being the reception of the ccession of sounds, periods of silence, musical notes, and their modu- tions, together with the peculiarities of articulate speech, things which re all inherently and essentially connected with the lapse of time, the The ear is the organ of time.

The eye is the organ of space.

ear is in a philosophical sense the time organ; that, the function of the eye being the estimation of extents, the position of objects, their sizes and apparent distances, this apparatus is, in reality, the space organ, its indications in this particular being rendered more perspicuous and more intense by its quality of being affected by variations of color; that as the tactile mechanism is affected by extraneous forces, such as pressures, estimating their degree of power, and being likewise influenced by things which are at a distance, the temperatures of which are different from the standard which it observes, but not by electrical, magnetic, or luminous agencies, we may infer that its functions are limited to a relation with mechanical powers, strictly speaking, and to heat; that smell and taste, though conveniently treated of as separate functions, dependent on separate organs, are, in reality, allied in the determination of the chemical peculiarities of bodies, and respectively adapted to the appreciation of those peculiarities, according as the substance presented may have the gaseous or liquid form.

Touch is for pressure and temperature.

Smell and taste for chemical qualities of gases and liquids respectively.

OF HEARING.

The organ of hearing is composed of three parts, the external ear, the tympanic cavity or tympanum, and the labyrinth.

Of the external ear.

The external ear consists of, 1st. The pinna, which is for the purpose of collecting soniferous waves, and directing them into, 2d. The meatus auditorius or auditory canal, a tube about an inch long, and extending to the tympanum. It is not perfectly cylindrical, its vertical diameter being the greatest, and it is curved so as to be concave downward. The interior is protected by hairs, and by a waxy secretion of the ceruminous glands.

Of the tympanum.

The tympanum, tympanic cavity, or middle ear, is within the petrous bone. It is bounded exteriorly by a thin oval membrane, the membrana tympani, which is placed obliquely across the meatus, at an angle of about 45 degrees, its outward plane looking downward. Across the tympanum there is a chain of three small bones, the malleus or hammer, the incus or anvil, and the stapes or stirrup. The malleus is attached by its handle to the membrana tympani, and the stapes, which is at the other extreme of the chain, is fastened by its foot-plate to the membrane of the fenestra ovalis. To the short process of the malleus, the tendon of the tensor tympani is attached, and to the neck of the stapes the stapedius. Besides these, other muscles of the tympanic cavity may be doubtfully mentioned, as the external muscle or laxator tympani, and the laxator tympani minor. Into the tympanic cavity there are ten openings, of which the more important ones are, 1st. That of the meatus auditorius; 2d. The fenestra ovalis, which is of an elliptic

shape and opposite the preceding, the foot-plate of the stapes, as has been said, being placed upon it; it is also sometimes called fenestra vestibuli; 3d. Fenestra rotunda, which is below the preceding, and separated from it by the promontory. From the circumstance that it leads from the tympanum to the cochlea, it is also called fenestra cochleæ: like the preceding, it is closed by a double membrane; 4th. The Eustachian tube, which extends from the anterior of the tympanum to the pharynx; and, 5th. The mastoid cells. The smaller openings are for the passage of various nerves and muscles.

The labyrinth, called likewise the internal ear, consists of three parts, the vestibule, the semicircular canals, and the cochlea.

The vestibule has three corners, an anterior, a superior, and a posterior, termed its ventricles. There open into it the fenestra ovalis, the scala vestibuli, and the five openings of the three semicircular canals. Besides these there are some smaller ones, as the aqueduct of the vestibule, and foramina for small arteries, and for the branches of the auditory nerve. The semicircular canals are three bony semicircles opening into the vestibule: upon one of the branches of each there is a dilatation, the ampulla. The three canals are respectively placed in planes at right angles to each other. The cochlea is a spiral bony canal raised upon a central axis, the modiolus: its interior is divided into two passages or scalæ by the lamina spiralis. These communicate at the apex of the cochlea through a small aperture, their other extremities opening differently; the scala vestibuli into the anterior ventricle of the vestibule, and the scala tympani through the fenestra rotunda into the tympanum. The labyrinth contains interiorly a membrane, the membranous labyrinth. Between the membranous labyrinth and the bony, a liquid, the perilymph, intervenes; the membranous labyrinth being also filled with liquid, the endolymph. There is no perilymph in the cochlea.

Of the labyrinth.

Of the three portions of the ear, the external canal is, of course, full of air, as is also the tympanic cavity or drum; but the labyrinth, as we have seen, is filled with a liquid, and in this the terminal filaments of the auditory nerve are placed.

The essential part of the mechanism of hearing is the auditory nerve, which arises from the anterior wall of the fourth ventricle, and then, joining the facial, passes forward upon the crus cerebelli; reaching the meatus, it divides into two portions, the cochlear and vestibular nerves, which subdivide again, and are distributed to the vestibule and cochlea respectively in the manner hereafter explained.

Of the auditory nerve.

VIEW OF EXTERNAL, MIDDLE, AND INTERNAL EAR.

Fig. 183: *a*, *a*, pavilion and external auditory canal, or external ear;

Fig. 183.

External, middle, and internal ear.

b, tympanic cavity, containing the bones; *c*, hammer and its three muscles, viz., *d*, internal muscle, lodged in the thickness of the superior wall of Eustachian tube, and bending at a right angle to be inserted in superior part of handle of hammer; *e*, anterior muscle of hammer; *f*, external muscle of hammer; *g*, interior half of membrana tympani, holding the handle of the hammer; *h*, tube of Eustachius; *i*, internal ear or labyrinth.

TYMPANIC CAVITY, ITS BONES, MUSCLES, AND NERVES.

Fig. 184.

Tympanic cavity.

Fig. 184: *a*, hammer, holding, by the anterior and superior part of its handle, and by its round extremity, *b*, the membrana tympani; *c*, internal muscle of hammer; *d*, stirrup upon fenestra ovalis; *e*, muscle of stirrup; 1, facial nerve, communicating with, 2, great superficial petrosal, and, 3, little superficial petrosal; 4, chorda tympani; 5, 5, nervous twig of internal muscle of hammer, arising from motor portion of fifth pair, and traversing otic ganglion; 6, nervous twig, arising from facial and going to muscle of stirrup; 7, ganglion of Gasser.

DIAGRAM SHOWING THE FACIAL IN THE AQUEDUCT OF FALLOPIUS AND ITS ANASTOMOSES.

Fig. 185.

Facial in the aqueduct of Fallopius.

Fig. 185: 1, facial; 2, nerve of Wrisberg; 3, petrosal twig of vidian nerve; 4, ganglion of Meckel; 5, little petrosal of Longet; 6, twig of muscle of stirrup; 7, auricular twig of Arnold; 8, chorda tympani, cut; 9, ganglion of Andersch; 10, nerve of Jacobson, divided into six twigs, viz., 11, twig anastomosing with, 12, carotid plexus, 13, twig anastomosing with great superficial petrosal (little deep petrosal of Arnold), 14, little superficial of Arnold, uniting with little petrosal of Longet to form 15, a common trunk, which goes to 16, otic ganglion; 17, twig of fenestra rotunda; 18, twig of fenestra ovalis; 19, twig of tube of Eustachius.

Common hypothesis of the function of the *auditory parts.*

The explanation usually given of the functions of these various parts is as follows: The waves of sound, moving through the atmosphere, pass down the exterior canal and strike upon the membrane of the drum, which is thrown into vibration there-

by. The little bones which form a chain from this membrane to the oval one at the back of the drum participate in this movement, and, indeed, serve to convey it, without much loss, across the cavity. It is considered that this is their function, since it may be proved experimentally that wave sounds going through such a solid combination, surrounded by atmospheric air, pass with but very little loss of intensity. Under the impulses thus communicated to it, the oval membrane commences to vibrate, and in those movements the water in the labyrinth joins; and so the filaments of the auditory nerve become affected, and the sensation of sound is transmitted to the brain. It is supposed that the three semicircular canals, which are set at right angles to one another, as it were, occupying the three adjoining faces of a cube, are for the purpose of determining in what direction the sound is coming—whether upward, downward, or laterally. Moreover, it is believed that the little muscles which operate on the membrane of the drum have the duty of tightening or slackening it so as to receive the sounding waves in the most available way.

Criticisms on this hypothesis.

It is not necessary to enter on a lengthy criticism of this explanation. Physiologists have long regretted that it assigns no use for many of the most complicated and delicate arrangements connected with the ear, offers no explanation of the manner in which that intricate organ is enabled to present to the mind the various relations of sound, and is inconsistent with many of the facts of comparative anatomy. Indeed, it is very plain that a true interpretation of the action of the different regions and structures of the ear can only be given from a conjoint study of the physical nature and properties of sounds, of the peculiarities of the soniferous waves which it is necessary for us to perceive, of the comparative anatomy of the ear as presented in all tribes of life; and, since there must be a correspondence among the lower tribes—perhaps we might have said the higher too—between the organs of voice and the organs of audition, the obscure points in the structure of the latter may be illustrated by what is known of the former. To these might be added the study of its embryonic development. It is by the aid of these different means that I pass to the description of the function of audition.

Proper mode of obtaining a true interpretation of these functions.

Three physical peculiarities of sound.

What, then, are the physical peculiarities existing in the waves of sound which we actually perceive? They are these three, 1st. The intensity, that is, loudness or feebleness of the sound; 2d. Its note or pitch; 3d. Its quality; for two sounds of the same intensity and note may differ characteristically. The sound of the violin differs from that of the flute, and this, again, from that of the human voice. Our organ of audition is so constructed that it is affected by each of these peculiarities, and transmits them to the mind.

In this respect we may speak of it as a perfect organ; for all mathematicians who have written on the subject of sound agree in setting forth the three peculiarities that have been mentioned, intensity, note, quality, as the grand features of waves of sound, and this upon a mere abstract discussion of acoustics. Now these three essential, abstract, or theoretical peculiarities of sound-waves are the very three which the organ of hearing seizes upon, and so we are justified in saying that, in this respect, it is perfect in its construction. Premising the remark that mathematicians have abundantly proved that the intensity of sounds depends upon the amplitude of excursion of the vibrating particles, and the pitch or note upon wave length, I shall now proceed to offer some arguments in proof of the proposition that the triple function of the ear is discharged in the following way: 1st. That the drum is for the measurement of intensity; 2d. The cochlea for the recognition of wave length; 3d. The semicircular canals for the appreciation of quality. I shall endeavor to show that the ear is not a homogeneous organ, as the older hypothesis supposed, but that one or other of these instrumental parts may be absent, and with it will disappear its special function, fortifying this view with facts presented by comparative anatomy, by embryonic development, and also by the relations of the voice, and showing the parallel between the structure and functions of the ear, the organ for normal vibrations, and of the eye, the organ for transverse ones; and the analogy and the identity of their embryonic development; that, for instance, the drum is the equivalent of the iris, and the cochlea of the retina and its adjacent parts.

Function of the drum, cochlea, and canals.

1st. On the measurement of the intensity of sound, structure of the tympanic cavity or drum, and its functions.

Structure of the drum and its functions.

The tympanic cavity or drum of the ear, as we have briefly described, is an air cavity of a cylindroid and flattened shape, in the petrous portion of the temporal bone. Outwardly it is bounded by the membrana tympani, and on other sides by the petrous bone: it is crossed by a chain of bones, three in number, and named the malleus or hammer-bone, the incus or anvil, and the stapes or stirrup. The Eustachian tube affords a channel of communication from the interior of the drum to the pharynx. Moreover, there is a communication with the mastoid cells, but the Eustachian tube is the only outlet to the atmosphere. The whole cavity of the tympanum is lined with mucous membrane and ciliated epithelium, which is also reflected over the bony chain. Upon the inner wall of the tympanum are two chief apertures, the fenestra ovalis and the fenestra rotunda, each closed by membrane. The chain of bones is attached at one end by the handle of the malleus to the membrana tympani, at the other by the foot of the *stirrup to* the membrane of the fenestra ovalis.

It is to be remarked that the membrana tympani is placed obliquely ıt the bottom of the external canal. In a hollow bony cone, ising upon the interior wall of the tympanum, and called the yramid, the stapedius muscle is placed. Through a little perture at the apex of the pyramid its tendon goes out, and is inserted n the neck of the stapes. Its action seems to be to make pressure on he membrane of the fenestra ovalis, but as it does this, it tilts the stapes nto an oblique position. A second muscle, the tensor tympani, is atached in front to the under surface of the petrous bone, and is inserted n the short process of the malleus; when it contracts it makes tension ipon the membrana tympani, drawing it more tightly inward. It is to e especially remarked of both these muscles that they are voluntary; hat is, of the striated variety. Two other muscles are described by ome anatomists, and have been indicated in *Fig.* 183 and 184. Their xistence, however, is disputed by others.

Action of the stapedius and tensor tympani.

In the opinion of Mr. Toynbee, the action of the two voluntary musles of the ear is as follows. By the tensor tympani the ase of the stapes is pressed inward toward the vestibule, as s a piston in its cylinder, and, as soon as the muscle ceases o act, the elastic ligaments which attach the circumference f the base of the stapes to that of the fenestra ovalis draw it out again. The stapes is moved by two muscles, the tensor tympani and the stapelius, it being commonly supposed that the latter aids the former in pressng the stapes inward, but he shows that it rotates the base of the stapes nd withdraws it from the cavity of the vestibule. This may be demontrated by pulling the stapedius, when the fluid in the scala vestibuli vill be found to move correspondingly. He therefore asserts that the tapedius is the antagonist of the tensor, the former relaxing the labyinthine fluid, membrana rotunda, and membrana tympani, the latter endering them more tense. Agreeably to this, the stapedius is supplied rom the portio dura, and the tensor from the otic ganglion. This contruction might lead to the supposition that the tensor affords protection rom loud sounds, and the stapedius enables the most delicate whisper to e heard, as in listening. Together they regulate the amount of sonoous vibrations which enter the labyrinth. Hence the effect of the detruction of the membrana tympani is to make sounds unendurable. In onfirmation of this is quoted the case of a patient who, under those cirumstances, could not bear the whistling of another patient in an adjoinng bed, and the observation of Cheselden that a dog, in which both nembranæ tympani had been destroyed, for some time received strong ounds with horror.

Mr. Toynbee's views of the action of the stapedius and tensor tympani.

We shall now present some reasons for supposing that the function f the tympanum is for determining the first property of sounding waves, hat is, *their intensity*.

Of the determination of the intensity of soniferous waves.

It has been proved by the experiments of Savart and Müller, that when the tension of the membrana tympani is increased, sonorous undulations pass with less readiness through it. Indeed, this may be verified by personal experiment, as when, by a strong effort of expiration or inspiration, the mouth and nostrils being closed, we compress air into the tympanic cavity or withdraw it therefrom through the Eustachian tube, and thereby stretch the membrana tympani outwardly or inwardly, the hearing at once becomes indistinct, and sounds are enfeebled. The same ensues on going down in a diving-bell, or suddenly ascending in a balloon. Of the former effect, Dr. Colladon gives the following account during a descent in a diving-bell at Howth in 1820. "We descended," says he, "so slowly that we did not notice the motion of the bell; but as soon as the bell was immersed in water, we felt about the ears and forehead a sense of pressure, which continued increasing during some minutes. I did not, however, experience any pain in the ears, but my companion suffered so much that we were obliged to stop our descent for a short time. To remedy that inconvenience, the workmen instructed us, after having closed our nostrils and mouth, to endeavor to swallow, and to restrain our respiration for some moments, in order that, by this exertion, the external air might act on the Eustachian tube. My companion, however, having tried it, found himself very little relieved by this remedy. After some minutes we resumed our descent. My friend suffered considerably: he was pale; his lips were totally discolored; his appearance was that of a man on the point of fainting; he was in involuntary low spirits, owing perhaps to the violence of the pain, added to that kind of apprehension which our situation unavoidably inspired. This appeared to me the more remarkable, as my case was totally the reverse. I was in a state of excitement resembling the effect of some spirituous liquor. I suffered no pain. I experienced only a strong pressure around my head, as if an iron circle had been bound about it. I spoke with the workmen, and had some difficulty in hearing them. This difficulty of hearing rose to such a height that during three or four minutes I could not hear them speak. I could not, indeed, hear myself speak, though I spoke as loudly as possible, nor did even the great noise caused by the violence of the current against the sides of the bell reach my ears."

Deafness in the diving-bell.

Action of the muscles of the tympanum.

Under natural circumstances, a stretching of the membrane inwardly is accomplished by the contraction of the tensor tympani muscle, the stapedius holding tight contemporaneously on the loop of the stirrup, and preventing disturbance of position of the bony chain at that end, and hindering any outward bulging of the me... ...estra ovalis. When, therefore, the soniferous waves ... ...embrana tympani, they tend to throw it into vibra-

tion; the tensor tympani contracts to such an extent as to bring the membrane to a standard of tension, and, since this muscle is of the voluntary kind, the mind judges of the degree of force which is required to produce that result just as, when we lift from the ground bodies of different weights, we judge with a certain precision of the degree of force necessary to be put forth. The condition of contraction of the tensor tympani therefore enables the mind to measure the intensity of the sounding waves.

But this muscular contraction is strictly a reflex act, and is therefore preceded, as all such acts are, by an impression. That impression is made, as we shall presently find, primarily on the auditory nerve. But since these reflected acts are not sensory, the mind has no knowledge of the effect impressed in this respect upon the auditory nerve, and only becomes sensible of it in an indirect way, through the contractions which have ensued in the tensor tympani muscle.

Use of the Eustachian tube.

In this view of the case, the use of the Eustachian tube becomes obvious; it is to form a ready passage for the air inwardly or outwardly, so that no condensation or rarefaction shall occur within the tympanic cavity; for such rarefactions and condensations would disturb the action of the contracting muscle, and make it yield a false estimate. Besides this, the Eustachian tube, as has long been known, affords an outlet for mucus.

Function of the ossicles.

In the explanation here presented, the function of the ossicles is rather for the purpose of tension than of conduction, though it is not denied that sounds may pass readily along them. They are to be regarded as aiding in the perfection of auditory perceptions, but yet not as being absolutely essential to the appreciation of sounds, or even of their finer modifications. Whatever affects the facility of vibration of the membrana tympani, such as its thickening, or stiffening, or unusual dryness, will render the hearing dull, but the membrane itself may be perforated, or even undergo extensive lesions, without any apparently corresponding effect. But if the stapes be injured or be removed, deafness is at once the result.

Precision in estimating the contraction of the auditory muscles.

There is nothing remarkable in the precision with which the contractions of the two muscles which stretch the membrane of the drum are made. The same precision is illustrated in the case of the muscles which adjust the vocal cords. The state of these may be determined to the $\frac{1}{17000}$ part of an inch.

It might perhaps be inquired, Why should not the function of determining the intensity of sounds, as well as their wave length, be imputed directly to the auditory nerve? It is with the ear as with the eye, the mechanism for determining wave length can only act with uniformity when the agent to be measured is reduced to a standard intensity. A

bright light falling upon the eye brings on a contraction of the pupil. And so with the ear. A partial deafening must be established to adjust the intensity of sound, that the auditory nerve may act under standard circumstances. The primary impression therefore made upon that nerve by the loudness of sounds is, so to speak, consumed by being converted as a reflex act into motion, because there is a necessity that the tensor and stapedius should move, and reflex acts do not affect the mind, but it instantly perceives the condition of contraction of those muscles, and so estimates the intensity of the sound.

2d. On the measurement of wave length, or time of vibration of sounds. Structure of the cochlea and its functions.

The structure of the cochlea is so significant that its true function has been long ago more or less distinctly recognized. Thus Dr. Young speaks of it as a micrometer of sound. Many physiologists regard it as determining the note or pitch. Any one who remarks the gradually decreasing width of its spiral lamina, and the manner in which the ultimate filaments of the auditory nerve are spread thereon, becoming shorter and shorter as they ascend the scale—who recalls the structure of the harp, or gradually shorter strings of the pianoforte, could scarcely fail of being impressed with the truth of this conclusion. The function of the cochlea is the determining of wave length, that is, the time of vibration or note of sounds.

Structure of the cochlea.

The cochlea has been described as resembling a snail's shell in appearance. It is a conical tube, wound spirally, and making two and a half turns. The interior of this conical and spirally-winding tube is divided throughout its length into two portions by means of a transverse partition, which, following the spiral winding of the tube, has had the name of lamina spiralis bestowed on it. The two partitions produced by the intervention of this lamina are called scala vestibuli and scala tympani. At the top or point of the helix the two scalæ communicate through a little hole, from the cessation of the lamina spiralis. To this opening or deficiency the name of helicotrema is given. Considering the two scalæ as separate tubes, their mouths open differently; the scala vestibuli opens into the vestibule of the labyrinth, and we may therefore regard the membrane of the fenestra ovalis as being virtually its boundary or closure, but the mouth of the scala tympani is against the fenestra rotunda, and is closed by the membrane of that aperture. As their names therefore indicate, the scala vestibuli opens into the vestibule, and the scala tympani into the tympanum.

The two scalæ.

Passing directly through the body of the cochlea, and being, as it were, the core upon which that structure is built, is a bony cone, called the modiolus. Indeed, the bony part of the transverse plate which separates the tube of the cochlea into

Introduction of the auditory nerve.

s two scalæ, might be regarded as a spiral process of the modiolus. 'hrough the modiolus and its spiral process, or lamina spiralis, the au-itory nerve gains access, through suitable channels, to the interior of ıe scalæ.

Fig. 186.

Interior of the cochlea.

Fig. 187.

Section of the cochlea.

Fig. 186, interior of the cochlea, rendered visible by the removal of half of the outer wall: *a*, *a*, lamina spiralis, turning by its inner edge, *b*, around the axis of the cochlea; *c*, infundibulum; *d*, aperture of communication between two scalæ; *e*, *e*, section of the outer wall; *f*, *f*, *f*, inferior or tympanic scala; *g*, *g*, *g*, superior or vestibular scala.

Fig. 187, section of the cochlea in the direction of its axis: *a*, canals of the axis, or of the columella, for the passage of the vascular and nervous ramifications; *b*, infundibulum; *c*, base of the modiolus, or columella; *d*, *d*, *d*, section of spiral lamina; *e*, *e*, *e*, section of the outer wall; *f*, *f*, *f*, inferior scala; *g*, *g*, superior scala.

The spiral lamina.

It is necessary to understand the structure of the lamina spiralis more ırticularly. As we have said, it divides the helical tube into ıe two scalæ by extending transversely across it. Its bony porɔn does not, however, extend more than about one third of the distance, ıe rest of it being made up in part of a delicate membranous portion, ıd completed by a muscular structure; so that, if we consider the lamıa spiralis at any point, the region of it near the modiolus is bone, the ıtermediate portion membranous, and the residual is muscular. Or, ınsidering the lamina spiralis in the aggregate, we might say that it ınsists of a helix of bone, membrane, and muscle. To the muscle the ıme of the cochlearis is given. Its obvious function is to tighten the embranous region. Moreover, considered thus in the aggregate, the mina spiralis is a triangular plate wound round upon a central conical ıre, and which, therefore, is broadest at the base of the cochlea, and adually tapers off toward the apex. It is to be understood that the ɔchlea, like all other portions of the labyrinth, is filled with water.

Upon the spiral lamina, issuing forth through its bony portion, are aced the ultimate filaments of the auditory nerve. These, having cast f their white substance, come into relation with elongated vesicles, ıd are thus distributed upon the membranous portion, the membrane ıing kept uniformly tense by the action of the cochlearis muscle.

Fig. 188, p. 370, section of the cochlea through its axis, magnified four ameters, and showing the cochlear branch of the auditory nerve, ac-

Fig. 188.

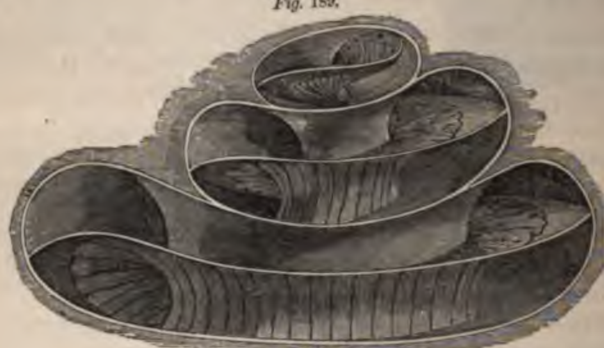
Magnified section of cochlea.

companied by some vascular ramifications across the conduits of the columella to the spiral lamina.

Fig. 189, section of the cochlea, magnified six diameters, to show the distribution of the cochlear branch of the auditory nerve from its perforation of the columella to its termination on the spiral lamina.

Figs. 190, 191, showing the middle and internal ear by a section of the superior face of the petrous bone, and principally the entire distribution of the auditory nerve: *a*, *a*, hammer, holding, *b*, *b*, *b*, its internal muscle; *c*,

Fig. 189.



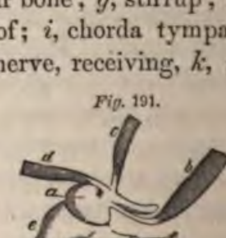
Distribution of cochlear nerve.

Fig. 190.

General distribution of auditory nerve.

c, *c*, its anterior muscle; and, *d*, its external muscle; *e*, *e*, anvil; *f*, lenticular bone; *g*, stirrup; *h*, muscle thereof; *i*, chorda tympani; *j*, facial nerve, receiving, *k*, great su-

Fig. 191.



The ossicles and their muscles.

perficial petrosal; *l*, cochlea; *m*, auditory nerve; *n*, its cochlear branch; and, *o*, its vestibular branch, furnishing, *p*, branch of posterior vertical

nal; q, branch of sacculus; r, branch of utricle; s, branch of horizon-l canal; t, t, branch of superior vertical canal.

We proceed now to the consideration of the functions of the cochlea.

Functions of the cochlea.

The principles of acoustics would lead us to infer that sounds entering e cochlea throw into vibration its spiral lamina, an inference hich is supported by anatomical considerations in regard to e position and function of the cochlearis muscle in keeping the mem-anous portion of the lamina at a due degree of tension. We should so infer that each external sound does not throw the lamina into vi-ation throughout its whole length, but only on a special and corre-onding point, and thereby affects solely the filament of the auditory rve in connection with that point; that sounds which are low will act on the broader portions of the membrane, near the mouth of the coch-, and those which are high, the narrower portions near the apex. In is respect, therefore, the function of hearing should have two limits, e for low and the other for high notes, as experience proves to us is tually the case; but possibly the scale is, so to speak, enlarged through e various degrees of tenseness which may be given by the contractions the cochlearis muscle. A general idea of the nature of this limited bration may be obtained by recalling the effect which is oduced when one musical instrument is played in the vi-nity of another, as when, for example, a flute is played ar to a piano-forte, the strings of the latter are thrown into sympathetic bration, and the piano emits a note answering to each note of the flute. ll the strings are not thrown into vibration at once, but for each note the flute that string of the piano vibrates, the length and tension of hich are duly adjusted. The same thing, again, may be seen when usical sounds are originated near a stretched membrane, the surface of hich has been dusted over with grains of dry sand. The whole sheet the membrane is not cast into vibration at once, but some parts move d some remain at rest, and so the sand-grains dance up and down on e vibrating parts, and soon, being cast therefrom, accumulate on the rts that are still, and mark out what are termed nodal lines. These dal lines, or places which are motionless, are frequently of remarkable mplexity and symmetry, as may be seen from the figures of them given any of the books on natural philosophy.

Physical illustrations of the action in the cochlea.

Course of sounds to the cochlea.

It is immaterial in what manner the sound has reached the cochlea, hether through the auditory canal or through the bones of e skull generally; the effect, as far as the spiral lamina is ncerned, will be the same in both cases. That sounds can iciently reach the auditory nerve, and produce thereupon their proper ect, without ever having passed through the auditory canal or the drum, manifested by a great many familiar facts. We still continue to hear

distinctly, though not so plainly, when the external canal is closed by some obstruction—nay, even when the sound-giving object, as a watch, is put into the mouth. So it would appear that the function of the cochlea is, in a certain sense, independent of the drum, though we have to admit that, for the precision and perfection of hearing, the latter is necessary.

The cochlea measures the time of vibration of sounds.

In the view here presented, I consider that each external musical note causes a special portion of the spiral lamina to vibrate, and that the particular nerve fibril supplying that portion is affected thereby, and thus a distinct sensation is communicated to the brain, the nerve fibrils to the right and left of the one affected lying at rest. It may probably be that the denticulate structure described by Drs. Todd and Bowman has for its duty the more perfect production of this isolated effect, or that the teeth thereof act like the dampers of a musical instrument, and restrain the vibration. Notes the wave length of which is great, or, what is the same thing, the times of the vibrations of which are long, affect those portions of the spiral lamina which are broad and near to the base of the cochlea, but notes whose wave lengths are short, and times of vibration correspondingly brief, affect those portions near to the apex. But probably the scale is changed, as before said, by the tension of the cochlearis muscle, and thus the same part of the lamina can take charge of a range of many octaves.

The scalæ are an interference mechanism.

It may be inquired how it is that a sound passing through the auditory canal, the bones of the tympanum, the membrane of the fenestra ovalis, and thus affecting its destined portion of the lamina, does not give rise to an idea in the mind of repetition or reverberation by moving back and forth through the two scalæ, and affecting its proper nerve fibril at each passage. Is there not a necessity for the existence of some mechanism of interference which shall destroy the wave after it has once done its work? Admitting the force of such inquiries, we can not avoid being impressed with the fact that the two scalæ into which the cochlear tube is divided present all the aspects of a mechanism constructed for the discharge of such a duty. For interference to take place among undulations of any kind, waves upon water, sounds in the air, or the ethereal undulations which constitute light, the essential condition is that they shall run through paths of unequal length, the inequality being one of a series of numbers. They must also be brought, for a full practical effect, to their common point of encounter under a very acute angle, and these conditions are represented in the scala vestibuli and the scala tympani, which are of unequal length, placed at such an acute angle to one another that they might almost be said to be parallel, occupied by a fluid of the same density, and through both at *the same* moment are passing the undulations which constitute the same

one having been communicated by the fenestra ovalis, the other ı the fenestra rotunda, their common point of convergence, and ; of mutual destruction, being at the helicotrema, the aperture at x through which they intercommunicate. Nor can we fail to be by the circumstance, if this explanation of the function of the e correct, in what an admirable manner the whole in- ıt is provided with self-adjusting power, since, when rup forces in the membrane of the fenestra ovalis, the e which is communicated through the water pushes out the mem- f the fenestra rotunda, and thereby the relative length of the two ıas changed, the one having become longer by as much as the as become shorter, an adjustment necessary to bring about total ence at the helicotrema. And we might add that such a con- ɒn is all the more interesting, for, since it is the intensity of the that is to be destroyed, reliance is had upon the intensity instru- he drum, to produce that effect, and it is done by the contractions tensor tympani and stapedius muscles. Perhaps the perfect ac- shment of this interference is the standard, to which allusion has ade before, by which the mind judges of the power which has been th by those muscles, and thereby of the intensity of the sound.

Adjustment of the length of the scalæ.

n the comparative anatomy of the cochlea and the character of the rgans, M. Duges formerly came to the conclusion that hlea has for its function the determining of the pitch ıds. In man, whose vocal powers are most varied, it in the highest perfection; in birds, whose vocal powers are more ed, it is reduced to a short and slightly curved tube, but still di- ıy a longitudinal septum; in reptiles, it exists only in a rudiment- te.

Comparative anatomy of the cochlea.

necessary existence in the ear of some mechanism for the purpose enting reverberation or repercussion has long been recognized writers on acoustics and by physiologists. Thus an explana- the functions of the semicircular canals and of the cochlea upon nciple is given by Dr. Roget, in his Bridgewater Treatise; and, manner, Professor Jackson, of Philadelphia, has for several years a similar doctrine in his lectures. Since 1840, I have in my pub- ures presented the explanation given in the preceding paragraphs. rs essentially from that of my friend, Professor Jackson (of which statement may be found in Dr. Smith's edition of Carpenter's logy, Philadelphia, 1855), in this, that it limits the accomplish- f interference to the cochlea. The view which I entertain respect- function of the semicircular canals will be immediately set forth: not appear to me that they are in any way connected with the in- ıce mechanism.

3d. On the determination of the quality of sounds, the structure of the semicircular canals, and their function.

Structure of the semicircular canals.

The semicircular canals are cylindroid tubes, developed, as it were, from the vestibule, and of a figure which has suggested their name. They are three in number, and placed at right angles to one another: two of them are vertical, the third horizontal; they all open into the vestibule, the adjacent branches of two of them coalescing first. On one of the branches of each of them there is a dilatation just before it joins the vestibule; to this dilatation the designation of ampulla is given. The vestibule of the labyrinth may therefore be regarded as the common mouth of the semicircular canals, and of the scala vestibuli of the cochlea; or, considering its order of development, the vestibule may be regarded as the essential portion of the labyrinth, and the semicircular canals and cochlea appendices that have branched forth from it.

The vestibule and semicircular canals are lined with a membrane which, of course, copies their shape, yet it is not in contact with their bony walls, but is parted therefrom by a stratum of water, to which, as has been said, the name of perilymph is given; their interior is also filled with a liquid—the endolymph, it is called. The bony structure is called the bony labyrinth; this structure is the membranous labyrinth. A portion of the auditory nerve divides into three main branches, which present themselves for the supply of the ampullæ: the brush-like terminations of these are accommodated with an otolith.

ILLUSTRATIONS OF LABYRINTH OF LEFT SIDE.

EXTERNAL, OR TYMPANIC FACE OF LABYRINTH.

Fig. 192.

Tympanic face of the labyrinth.

Fig. 192: *a*, external wall of vestibule, on which is seen, *b*, fenestra ovalis; *c*, fenestra rotunda, and, *d*, tract of the facial nerve; *e*, superior semicircular canal; *f*, posterior semicircular canal; *g*, horizontal semicircular canal; *i*, *i*, *i*, wall of cochlea; *j*, aqueduct of cochlea; *k*, portion of petrous bone.

INTERNAL, OR CRANIAL FACE OF LABYRINTH.

Fig. 193.

Cranial face of the labyrin'h.

Fig. 193: *a*, internal wall of vestibule; *b*, aqueduct of vestibule; *c*, base of cochlea; *d*, aqueduct of cochlea; *e*, *f*, conduit, at the bottom of which are several holes for the passage of facial and auditory nerves; *g*, superior semicircular canal; *h*, posterior semicircular canal; *i*, horizontal semicircular canal.

INTERIOR OF LABYRINTH, SEEN ON ITS EXTERNAL OR TYMPANIC FACE.

Fig. 194.

nterior of labyrinth.

Fig. 194: *a*, vestibule, into which open the semicircular canals by five orifices, and the vestibular scala of the cochlea; *b*, *b*, section of the wall of the cochlea; *c*, *c*, bony portion of spiral lamina, dividing the conoid cavity of the cochlea into scala vestibuli and scala tympani; *d*, orifice at summit of cochlea.

INTERIOR OF LABYRINTH, SEEN ON ITS INTERNAL OR CRANIAL FACE.

Fig. 195.

erior of labyrinth.

Fig. 195: *a*, vestibular cavity, into which open the cavities of the semicircular canals and the cochlear cavity; *b*, bottom of internal auditory canal, answering to base of cochlea, and partly to internal wall of vestibule; *c*, simple foramen for facial nerve; *d*, many openings for auditory nerve.

Criticism on the explanation usually given of the function of the canals.

The explanation usually given of the function of the semicircular cas is, that they serve to determine the direction of sounds, idea which has arisen from their remarkable rectangular ition. However, this is accomplished in almost all cases directing the external canal toward the point from which sound is coming, and judging of its place by the varias of its intensity. Animals commonly direct the external ear toward sounding point, guided doubtless in the same way. Some physiolots have restricted the use of the semicircular canals to the collection hose sounds which strike upon the skull, but, besides the preceding siderations, there are others derived from comparative anatomy which m to indicate that this can scarcely be their duty.

They are for estimating the quality of sounds.

The intensity of sounds is judged of by the tympanum; their pitch wave length is determined by the cochlea, and therefore re arises a strong presumption that the semicircular cas must have the function of distinguishing the third charristic of sounds, that is, their quality; since, if this be not the case, re seems to be no other portion of the auditory mechanism to which t office could be assigned.

The suspicion which we are thus led to entertain, that the semicircucanals are for appreciating the quality of sounds, is strengthened in common degree by facts of comparative physiology. Unfortunately, know so little of the mechanical peculiarity on which distinctions of lity depend, that we are wholly unable to trace out the structural conions of an organ which should be calculated for seizing on them. We ow that the quality of a note emitted by a violin is different from that itted by a flute, though the intensity and pitch may be the same, but

we can not tell why. In the case before us, we therefore can expect no assistance in the way of arguments from mechanical philosophy, and are limited to the use of those which may be drawn from comparative anatomy and physiology.

Illustration of this explanation from comparative anatomy.

Examining, therefore, what appears to be the primitive plan of the construction of this mechanism, we find it to consist of a nerve fibril in connection with an otolith, or little stony body. Such a construction, included in a bag of water, constitutes, in point of fact, the organ of hearing of some of the lower tribes, as the gasteropodous molluscs. These animals can have no perception of the pitch of sounds or musical notes, and only an imperfect one of intensities. But what they do distinguish is one noise from another. Now the idea conveyed to the mind by difference of noises is precisely the distinction that we are dwelling on, that of quality.

General view of the auditory mechanism.

If, instead of restricting our examination to the semicircular canals, we extend it to the whole organ of hearing, and consider together, in the case of each animal tribe, its requirements, and the manner in which those requirements are satisfied, we shall meet with a surprising confirmation of the preceding views. The lowest requirement we can conceive of is the appreciating of noises; an advance upon this is the determination of their direction; a higher advance, the determination of their intensity; and a still higher, the recognition of those combinations of impulses which constitute a musical sound. For each of these successive requirements the auditory mechanism must necessarily become more complex; and thus it first appears, as we have just stated, as a sac of water, containing a stony grain or otolith imbedded in the œsophageal collar. A noise agitates the otolith, and by its movement the perception of a sound ensues.

Comparative anatomy of the ear.

In cephalopodous molluscs the auditory sac is detached, and the intercommunicating thread represents the rudiment of what, in the higher grade of development, will be the auditory nerve. With another advance the sac is lodged in a cartilaginous cavity. Thus, in the cuttle-fish, a simple cartilaginous vestibule exists, having within it a membranous bag or auditory capsule, filled with fluid, and upon the capsule the filaments of the auditory nerve are spread. An otolith or ear-stone is placed within, and this constitutes the entire apparatus, while yet there is no vibrating membrane and no fenestral aperture.

Even in still higher conditions the purely mechanical character of the structure is manifest, and so, in some of those in which the sac opens exteriorly, grains of sand, that have been introduced by chance from without, rest on the hair like filaments which the auditory sac contains, each filament apparently including a nerve fibril. In a still higher condition of advance, as, for example, in the lobster, a portion of the shelly wall which

forms the boundary of the auditory cavity is unconsolidated, and a membrane which stretches over the otherwise vacant space presents the first rudiment of the fenestra ovalis. With the exception of the amphioxus, all vertebrated animals have a special organ of hearing, which, in successive tribes, presents an interesting increase of complexity, beginning in the cyclostomes with a sac in the cranial cartilages filled with water, nerve fibrils distributed on its walls, and an otolith included, but no external communicating aperture. From this, in succession, the various portions which are to be developed in perfection in the higher races gradually appear: the myxine has one semicircular canal arising from the vestibule, the lamprey has two, the higher forms have three. As the case may be, a portion of the cartilage or bony parietes is deficient, and, again, the fenestra ovalis is the result. Though in the osseous fishes there is neither tympanum or cochlea, in some few the rudiments of the former begin to exist. The naked amphibia have no cochlea, and only one fenestra, answering to the ovalis: to this is fitted a stapes; but in lizards and scaly serpents there is a general advance, these having a conical cochlea. As we pass through them the plan is carried out; the tympanic cavity and its chain of bones, the Eustachian tube, and cochlea appear; and with the rudiment of the cochlea there is presented in the tympanic cavity a second aperture, answering to the fenestra rotunda. In birds the structure offers a continued improvement, commencing on a plan analogous to that of the scaly amphibia, but exhibiting a speedy development. The membrana tympani is composed of several layers; the cavity of the drum communicates with cells in the cranial bones, the analogues of the mastoid cells; a bony Eustachian tube crosses to meet its fellow of the opposite side, and open in a common aperture. The ossicles consist of a malleus, a staff-shaped intermediate bone, and a flat stapes, resting on the fenestra ovalis. As if to show a tendency to the form it is eventually to assume, this bone sometimes presents a forked appearance, the preparation for a stirrup shape. As regards this bone, birds and mammals may be said to overlap, for in its more developed condition in birds it bifurcates, but in the lower mammals, as the kangaroo, it is still cylindric. In birds of prey the semicircular canals are large, the cochlea fairly developed, though as a straight or slightly-curved tube, containing its scalæ and vibrating lamina: the vestibule has ear-stones. Through the monotremata this condition of construction is continued into the perfect mammals: all the aerial tribes have external ears, and full development is reached in the auditory mechanism of man.

Now if we collate the facts here presented with the requirement of the condition of life which each of these successive races seems to demand, we shall find that the remark heretofore made, that the semicircular canals are for the recognition of the qualities of sound, is strikingly borne out,

though, from our ignorance of what it is in which quality consists, we are wholly unable to offer an explanation of the precise mode of action of that part of the auditory mechanism.

Partial deafness of inferior animals.

We are so prone to extend our ideas of our own perceptions to the case of other animals that it may not here be unprofitable to offer a remark which may serve to correct such views. To many of the sounds with which we are familiar, birds and other lower tribes are totally deaf; they can not appreciate, except within a narrow range, the notes of music, and, indeed, to all those in which there is no cochlea such notes are inaudible. In the lower grades nothing more than a noise can be detected, and that doubtless in a very indefinite way. We can therefore understand how, through imperfection of construction, they are cut off from the perception of an infinite number of occurrences which are obvious enough to us. Even among our domestic animals, to which we so often speak or sing in the way we do to one another, the intellectual obtuseness which we think we recognize doubtless originates in an incapacity to receive those expressions, because of faulty structural condition.

Order of development of the ear.

In closing these remarks on the sense of hearing, it is necessary to direct attention to the order of development of the organ in the individual of the human species, as we have done in the case of the successive tribes of animals; and here it may be affirmed that the ear of man passes in a transient succession through all these permanent animal forms. It originates at first from a budding forth of the vesicle of the medulla oblongata, the issuing cell becoming by degrees pear-shaped, and connected with the parent cavity by a thread or stalk. The pear-shaped cavity is the rudiment of what is eventually to be the vestibule; the pedicle will become the auditory nerve. Even at this early period the cavity contains an otolith. By degrees there arises from the folding in of the walls of the vestibule the curved forms that are to become the semicircular canals, and, at a period a little later, in an analogous way, the cochlea. At one stage of this development the membranous labyrinth presents an almost identical aspect with that of the retina at the time, both being composed of a fibrous network interspersed with granules and nucleated cells, the shadowing forth of the parallelism of construction which may be traced in the two organs when they have reached their utmost development, the one for the cognizance of normal and the other for transverse vibrations.

Illustration of the imperfection of the doctrine of means and ends.

And so it appears that, as respects the organ of hearing, its order of development in the individual is identically the same as its order of development in successive tribes taken in the aggregate. In the latter case, we constantly regard its condition of construction as arising from a purposed adaptation

to the wants of the animal. We consider it as affording a series of illustrative instances of the use of means for the production of definite ends, and therefore as exhibiting the evidences of design; but what are we to make of the other, the parallel, the individual case, in which, in succession, the organ presents each one of these particular forms, and in which not one is ever used, save only the most complete, the last? There would seem here to be little of adaptation, little of means to an end, nothing of design. But does not this prove to us (and the other organs of sense will furnish a similar argument) that the development of the various animal tribes, and of each individual of those tribes, takes place under the operation of a far-reaching and common law, and that the particular condition which any species presents, or even any individual at some special period of his existence, is a manifestation of the degree or extent to which that law has been carried out?

CHAPTER XX.

OF VISION.

Analogy between Sound and Light.—Comparative Anatomy of Vision.—Perception of Warmth.—Structure of Ocelli.—Use of Lenses.—Physical Principle of the Organ of Vision.

Description of the Human Eye.—Optical Action of its Parts.—Spherical and Chromatic Aberration.—Receiving Screen of the Eye is the black Pigment.—Long and short Sight, and their Correction.—Limits of Vision are included in one Octave.—Limit in estimating the Brightness of Light.

Nervous Mechanism of the Eye: its Structure and Functions.—Manner of Perception by the Retina.—The black Pigment absorbs the Rays.—Single and double Vision.—Duration of Impressions.—Ocular Spectra.—Erect Vision.—Idea of the Solidity of Bodies.—Hypothesis of the Action of the Retina.

Accessory Apparatus of the Eye.—The Eyebrows.—Eyelids.—Lachrymal Apparatus.—Muscles of the Ball.

THE physical difference between waves of sound and waves of light has been already stated to consist in this, that the vibrations which give rise to the former coincide with the direction in which the wave passes, but those of the latter are transverse. Analogy between sound and light. There is, however, notwithstanding this difference, a general analogy between the structure of the ear and that of the eye, and provision must be made in the case of the organ of sight for determining the fundamental peculiarities which are necessary to be determined in the case of the organ of sound; that is to say, intensity, wave length, or time of vibration, and, in addition thereto, the requirements of this particular problem demand that means should be included for ascertaining with exactness the shape of objects and their relative positions.

Of the different methods which we might follow in the discussion of the mechanism of the eye, none, perhaps, is more satisfactory, or leads to clearer conclusions, than that which is presented by comparative anatomy. It is just as difficult to take a complicated organ, such as the eye of man, and from the study of it to deduce the significance of its various parts, as it would be to take a complicated human contrivance and determine from it the properties of its mechanical elements. It is scarcely from the watch or other delicate machine that we should expect to make plain the properties of the lever or the wheel, and experience shows that it is only by the attentive study of the cases presented by comparative physiology—those experiments made for us by nature, as CUVIER has called them—that we can hope to advance to the perfect solution of this problem.

Importance of the comparative anatomy of vision.

Treating the subject, therefore, in this way, we observe that, in the animal series, long before any thing like a distinct organ of vision can be detected, there is yet a perception of light and darkness. The hydra, a fresh-water polype, offers an example, for this animal seeks the sunny side of the vessel in which it is placed, preferring it to the shade. In the absence of every vestige of a visual organ, there can not be a doubt that its movements depend on the perception of warmth, just as when a man who is totally blind passes from the sun into the shade, his feelings at once notify him of the change. In a physiological sense, it is of no interest to us to inquire into the physical nature of this effect, whether light is identical with heat, or whether, when light falls upon a body, it turns into heat. We have only to accept it as a fact capable of abundant experimental proof, that, whenever rays of light fall on a surface, that surface becomes warm. This, as we shall now find, is the key of all the explanations we have to give.

Confused perception of warmth.

Dr. Franklin made an experiment to the following effect. He placed on the snow, on a sunshiny winter day, pieces of cloth of different colors—black, yellow, white, etc., etc.—in such a position that the sun's rays fell equally on them. After a certain length of time, on examining them, he found that the black cloth had melted its way deeply into the snow, the yellow to a less depth, and the white scarcely at all. He therefore drew the conclusion that, when they are receiving light, surfaces become warm in proportion to the depth of their tint, and that, of all surfaces, one having a velvety blackness is most sensitive, because it can exert the most powerful absorbent agency.

Dr. Franklin's experiment.

On this principle seem to be constructed the ocelli of the lower tribes. These consist of a collection of pigment granules, usually of a red, black, or dark color, seated on the expansion of a nervous thread. The principle which is clearly contained in this mechanism is that of relieving the general surface from

Ocelli of lower animals constructed on Franklin's principle.

the impression of light, or rather of rendering it more intense by centralizing it upon a special locality. Such a construction involves at once a change in the nervous mechanism, by devoting a particular system of nerve tubules to the new duty. But, notwithstanding this increasing complexity of structure, the physical principle is still as simple as before. It is indeed almost as though a blind man should paint upon his skin a black space, so that, as in Franklin's experiment, it might be more sensitive to the sun. With this devotion to a new duty the nervous tubules doubtless assume an isolated function, and thus there arises a nerve of special sense. The ocelli of the lower animals are sometimes quite numerous. From this a new power is at once derived, the power of determining the position of the source of light, a property which doubtless becomes more perfectly marked in proportion to the number and symmetry of arrangement of the ocelli. As we ascend the animal series in our examination, we soon find that complexity is being introduced. A membranous hood, arising from a little fold of the external tegument, shadows forth the rudiment of an eyelid, and seems to indicate to us that, even in these low grades, the condition which we shall eventually find so strikingly marked in the high ones already exists, that functional activity involves destruction, and that the sensory mechanism must have its period of repose.

Introduction of converging media.

Approaching the more highly-developed conditions of the organ of vision, we may next consider the cases presented by the eyes of insects and the eyes of higher mammalia. In these a new physical principle has been introduced, the optical property of the convex lens, a transparent solid, having one or both of its surfaces curved, and obtaining therefrom the power of forming representations, or images of objects which may be in front of it, at a certain focal distance behind. Such images are seen when we take a magnifying glass or a convex lens, and, holding a piece of paper behind it at a particular point, there will be depicted upon the paper the inverted forms of whatever objects may be in front. That distance is the focal length of the lens. But we may farther notice, and to this observation our attention will be required hereafter, that the focal length is variable. If the object be near, the focal length is greater; if distant, it is less.

The focus and its variations of distance.

The camera obscura.

The instrument known as the camera obscura represents the optical construction of the eye. Upon a receiving surface or screen, placed at the focal distance behind its lens, images are depicted of whatever objects may chance to be in front; but—and this is a remark of interest to us now—the visual range, or field of view, is quite limited. In animals, the perfection of whose vision requires that, instead of being restricted in their view to a narrow space, they should be able, as it

were, to take in almost a hemisphere at a glance, this extension of the visual function can only be accomplished in one of two different ways.

Different contrivances for embracing a larger field of view by the eye.

To use the illustration we have been employing, it may be reached by having innumerable cameræ pointing in innumerable directions, and conveying the resulting images to one common surface, or by having one, or at most two, cameræ set upon a movable stand, which can quickly point them in any direction, and so enable them to inspect successive fields of view with almost instantaneous rapidity. The former plan is resorted to in most insects, the latter in man. In insects, the immobility of the head upon the trunk would interfere with any rapid rotation of the visual organ; in man, the facility with which rotation can take place upon the neck as on an axis, and the movement of the eye in its orbit, accomplishes the object without any kind of difficulty.

In continuing an investigation of the structure of the eye, it is convenient to consider it under three heads: 1st. Its optical mechanism; 2d. Its nervous mechanism; 3d. Its accessory apparatus.

1st. *Of the Optical Mechanism of the Eye.*

The human eye is of a globular form, and about one inch in diameter.

The human eye.

It is not perfectly spherical, its lateral diameter being shorter than its antero-posterior by about one twentieth part. It may be described as consisting of three coats, which, forming a shell, contain transparent media and the optical apparatus. It might also be considered as arising from an expansion of the optic nerve into an almost spherical cavity, and which, being fortified by certain tissues behind, has a dioptric mechanism in front.

The coats of the eye are three in number: the sclerotic, the choroid, and the retina. The sclerotic, which is the exterior, is a white fibrous membrane, very tough, and possessing the necessary resistance to give mechanical protection to the parts within. Within this is the choroid, a vascular layer or tunic, presenting on its interior the black pigment which darkens the interior of the eye. The innermost coat is the retina, an expansion of the optic nerve. The sclerotic coat is perforated in front, and into the circular aperture so arising the transparent cornea is let, like a watch-glass. Many anatomists, however, consider that the cornea is absolutely continuous with the sclerotic, and a part of it; the sclerotic and the choroid are united round the edge of the cornea by the ciliary ligament. The iris is perforated in its centre, the aperture being designated as the pupil. Posterior to the iris is the crystalline lens, the space between the lens and the cornea being filled with the aqueous humor, in which the iris floats, dividing it into two regions, called, from their position, the anterior and posterior chambers. All the rest of the globe be-

tween the back of the lens and the retina is filled with a substance extremely transparent, and known as the vitreous humor. The aqueous humor, the crystalline lens, and the vitreous humor, by reason of their transparency, offer, therefore, no obstacle to the passage of light.

ILLUSTRATIONS OF THE EYE.

Fig. 196: *a*, *a*, sclerotic, turned over; *b*, choroid; *c*, *c*, ciliary nerves traversing sclerotic, and going between it and choroid; *d*, retina; *e*, vitreous body; *f*, crystalline; *g*, middle section of iris; *h*, middle section of cornea; *i*, anterior chamber; *j*, posterior chamber; *k*, canal of Fontana, between the ciliary circle and iris on one side, and sclerotic and cornea on the other.

Fig. 196.

Profile view of the eye.

Fig. 197.

Front view of the eye.

Fig. 197: *a*, transparent cornea; *b*, *b*, sclerotic; *c*, iris; *d*, pupil; *e*, ciliary circle; *f*, choroid, on which is seen the dichotomous termination of the ciliary nerves; *g*, ciliary processes; *h*, crystalline.

SECTION OF THE EYE.

Fig. 198: *a*, upper eyelid; *b*, lower eyelid, showing the different layers composing them; *c*, *c*, conjunctiva, reflected from posterior face of eyelid upon the anterior face of the globe of the eye; *d*, *d*, orbito-ocular aponeurosis, prolonged upon, *e*, the sheath of the optic nerve, and sending sheaths to the muscles; *f*, the superior rectus; *g*, the inferior rectus; *h*, *h*, sclerotic, re-enforced behind by sheath of optic nerve, and in front by aponeurotic expansion of recti muscles; *i*, transparent cornea, cut to show its lamellar texture; *j*, *j*, choroid; *k*, ciliary circle; *l*, ciliary body and processes; *m*, iris and pupil; *n*, *n*, canal of Fontana; *o*, *o*, retina, continuous with sub-

Fig. 198.

Section of the eye.

stance of optic nerve; *p*, ciliary circle of Zinn; *q*, *q*, hyaloid membrane; *r*, capsular artery, lodged in hyaloid canal; *s*, *s*, vitreous humor and its cells; *t*, crystalline and its capsule; *u*, *u*, canal of Petit; *v*, anterior chamber; *x*, posterior chamber.

To this general description of the conformation of the eye may be added a few remarks on each of its constituent parts.

The sclerotic coat.

The sclerotic coat consists of white fibrous tissue, which, in addition to the use before mentioned, affords the means of insertion of the muscular mechanism for moving the ball. It is thicker behind than in front, its relative thickness differing in different animals according to the mechanical circumstances to which they have to be exposed. In the whale, which has to resist the pressure of a deep sea, the sclerotic is an inch thick. In some instances cartilage is included in it, in others bone. Besides the aperture in front, into which the cornea is let, there is another behind for the passage of the optic nerve. This method of description, though very convenient, is, however, scarcely correct, if we consider the coats of the eye as arising from expansions of the optic nerve, for then the sclerotic answers to the exterior investiture, and the tubules of the nerve gain access to the interior of the eye without passing through an aperture, properly speaking. The place at which the nerve enters is not in the optical axis, but at a distance of about its own diameter on the interior side. The aperture is smaller on the inside of the sclerotic than on the outside; thus it presents a conical shape. It is not a single hole, but rather a collection of sieve-like openings, through which the optic tubules pass.

The cornea.

The cornea, which is let into the sclerotic in front, is of greater curvature than the sclerotic. Its front and back faces are parallel. Though it seems to be pellucid as glass, it has a very intricate construction, being composed of at least five separate layers; the innermost one, or cornea proper, consisting, it is said, of more than sixty lamellæ.

The choroid: its arrangement for introducing and removing blood.

The choroid coat is arranged, like the sclerotic, for the passage of the optic nerve. The iris is commonly described as a process of it. The choroid is a sheet of blood capillaries arranged in two layers, an arterial and a venous, in such a way as to give the utmost freedom of access for the arterial blood to the retina within. The veins which remove this blood are placed in curved forms, and are designated vasa vorticosa; from the choroid also the dark pigment is secreted. Those animals in which it is absent are called albinos. Near to the iris the choroid merges in the ciliary ligament, and gives forth the ciliary processes, being covered in front by the ciliary muscle.

Fig. 199: *a*, *a*, section of sclerotic; *b*, exterior surface of the choroid,

on which are seen, *c*, *c*, the vasa vorticosa; *d*, *d*, ciliary nerves; *e*, ciliary ligaments; *f*, anterior face of iris; *g*, pupil.

Fig. 199.

The veins of the choroid.

Fig. 200.

The arteries of the choroid.

Fig. 200: *a*, *a*, exterior surface of the choroid and the iris, showing the arterial network of these two membranes, supplied by the ciliary arteries, which, after having traversed the sclerotic, divide into, *b*, *b*, posterior ciliaries for the choroid, and *c*, *c*, anterior ciliaries for the iris.

The iris, though arising, as has been said, from the choroid, is constructed in a different way, its tissue mainly consisting of unstriped muscular fibre, except in the case of birds, which present the striped variety. It is extremely vascular, its arteries being derived from the ciliary. The color of the eye depends on the color of the front of the iris; the posterior portion is covered with black pigment. The iris.

The ciliary muscle, for such it has been proved to be by Dr. Wallace, of New York, is of the unstriped kind; its action is to move the lens. In birds it is of the striped variety.

The retina intervenes between the vitreous humor and the choroid coat; it arises from the tubules of the optic nerve, which have cast off their covering investitures on their passage through the sclerotic. It extends forward to the ciliary body; is perfectly transparent during life, though it soon becomes semi-transparent. Its structure, a knowledge of which is of the utmost importance in the theory of vision, will be presently described. The retina.

Fig. 201.

Yellow spot of Soemmering.

In the optical axis of the eye there is upon the retina a spot of about the twentieth of an inch in diameter, called the yellow spot of Soemmering. Its position is shown in *Fig.* 201. The entrance of the optic nerve is at the blind spot which is marked at some distance on one side. The vitreous humor is contained in a delicate mesh of transparent tissue, which causes it, when removed, to present the aspect of a jelly. In front it receives the crystalline lens, which is contained in a closed capsule. Round the lens there is a passage, known as the canal of Petit, which enables the ciliary muscle to move the lens. The The vitreous humor.

analysis of the vitreous humor shows that it consists of water containing about one and a third per cent. of common salt, with a trace of albumen.

The crystalline lens. The crystalline lens is a double convex of unequal curvatures, the anterior surface being the flattest, the shape changing with the period of life, as also does the density of its parts, its central portions being always the most dense. In construction it is extremely complex, being made up of fibres ranged side by side, and so forming successive laminæ. The fibres are about the $\frac{1}{5000}$ part of an inch thick. The refracting power of the lens differs at the centre and circumference: in the former region it is greater. In chemical composition, the lens consists of about fifty-eight per cent. of water, and thirty-six per cent. of a form of albumen known as globulin.

Aqueous humor. The aqueous humor fills up the space between the lens and the cornea: it is composed of water containing about one per cent. of common salt.

Of the Optical Action of the Eye.

Formation of images by lenses. It is the province of the works on natural philosophy to explain how, when rays of light fall upon a convex lens, or upon combinations of such lenses, an image of the object will form at the proper focal distance. For the purposes of physiology, it is sufficient to receive this as a fact, which may be easily illustrated by observing the images of external objects depicted upon a sheet of white paper when a convex lens or magnifying-glass is held at a particular distance between the object and the paper.

Effect of distance of the object and curvature of the lens. In making such an experiment, some other facts which concern the physiologist may be readily demonstrated: 1st. That the focal distance, that is, the distance between the lens and the paper, is variable: it is greater for objects that are near, less for those that are remote; 2d. That lenses of different curvatures being compared together, the flatter ones have the longest focus for objects at the same distance; 3d. That lenses of the same focus, but of different diameters, give images unequally sharp, an indefiniteness being perceived in the image given by the lens of large diameter. This indistinctness is due to the spherical figure of the lens, and would not have occurred had the surface been ground to another conic section. It is called spherical aberration; 4th. Unless the lens be of very long focus, or its aperture or diameter be very small, the edges of the images it yields will be fringed with rainbow colors, and thereby a second cause of indistinctness arises. It is called chromatic aberration. This aberration may be destroyed by properly *combining* together lenses made of different refracting media, and with

Spherical and chromatic aberration.

surfaces of suitable curvatures; a combination in which this has been effected is termed an achromatic lens; and if, at the same time, by proper arrangements, the spherical aberration has been destroyed, the lens is termed aplanatic.

Now the aqueous humor, as bounded by the cornea in front and the crystalline lens behind, acts as a convex, and therefore converging lens, and to this effect the crystalline itself adds powerfully, the two conjointly causing the images of external objects to form upon the black pigment. These images are, of course, inverted.

Convergent media of the eye.

The adjustment of the eye for perfect vision of objects at different distances is accomplished by the action of the ciliary muscle, the requisite movement being to draw the lens farther from the black pigment when the object is near. There has been much controversy as to the manner by which this adjustment for distance is effected, but it is generally now agreed that it is done in the manner just mentioned. There has also been a difference of opinion as respects the actual screen upon which the images form. Some of the early optical writers regarded the black pigment as being that receiving surface, an opinion which has been universally abandoned, the function having been of late attributed to the retina, but, as it appears to me, on totally insufficient grounds. The arguments against the retina, both optical and anatomical, are perfectly unanswerable. During life it is a transparent medium, as incapable of receiving an image as a sheet of clear glass, or the atmospheric air itself; and, as will presently be found, when we come to describe its structure, its sensory surface is its exterior one, that is, the one nearest to the choroid coat. But the black pigment, from its perfect opacity, not only completely absorbs the rays of light, turning them, if such a phrase may be used, into heat, no matter how faint they may be, but also discharges the well-known duty of darkening the interior of the eye, and therefore preventing indistinctness through the straying of the rays of light. Perfection of vision requires that the images should form on a mathematical superficies, and not in the midst of a transparent medium. The black pigment satisfies that condition, the retina does not.

Adjustment by the ciliary muscle for distance.

The receiving screen is the black pigment, and not the retina.

Spherical aberration is compensated for partly by the increasing density of the lens toward its centre, and partly by the action of the iris, which stops such rays of light as are at any considerable distance from the axis of the eye, acting in the same manner as a perforated plate or diaphragm in ordinary optical instruments.

Correction for spherical aberration.

It does not appear that there is any attempt at correcting the chromatic aberration of the eye, though it is popularly supposed that the cornea,

Chromatic aberration is uncorrected.

the aqueous humor, the lens, and the vitreous humor act together in the same manner as the different pieces of glass in an achromatic arrangement. Optical reasons, however, founded upon the constitution and refractive powers of those substances, lead us to abandon that view, and in a theoretical respect to regard the eye as imperfect in this particular.

Adjustment for the intensity variations.

Adjustment for the variable intensity of light is effected by the dilatations and contractions of the iris, the pupillary opening of which varies from the $\frac{1}{20}$ to the $\frac{1}{3}$ of an inch in diameter. We are thus enabled to bring to the same degree of illuminating effect upon the retina lights which differ in brilliancy in the proportion of one to forty-five. The means by which this is accomplished will be more particularly described when we speak of the nervous mechanism of the eye.

It has been already observed that the actual field of view at a given moment is quite limited. We are liable to deceive ourselves on this point from the rapidity with which the eyeball can be directed to different parts in succession.

Long and short sight, and their correction by spectacles.

In what has been said, reference is made to a perfect eye; but imperfections are very common. Two may be more particularly pointed out—long-sightedness and short-sightedness. In the former, objects, to be seen distinctly, must be placed farther off than the usual distance; in the latter they must be brought nearer. Long-sightedness arises from the flatness of the lens or cornea, so that the focal images given do not fall truly on the black pigment, but would be, at a certain distance, exterior to it; hence the indistinctness that results. Short-sightedness is due to an excess of curvature in the cornea or lens, the rays forming their focal images before the black pigment is reached. The former defect may be removed by the use of convex lenses as spectacles, the latter by concave. It is often said that short-sightedness is a defect of early life, long-sightedness of old age. However this may be in another respect, it is not so optically. Indeed, cases sometimes occur in which one eye is affected with the former and the other with the latter difficulty. Very frequently the two eyes, compared together, will be found differently advanced in their degree of imperfection, and hence the difficulty of obtaining a pair of spectacles, though the selection is attempted to be made out of a large assortment. In such cases, each eye should be accommodated with a lens to suit itself.

Limit of vision is one octave.

Compared with the organ of hearing, the eye is much more limited in its action; for, while the ear can distinguish sounds which vary through many octaves, the eye can only perceive vibrations *which, to* use the language of acoustics, differ by a single octave only.

To one octave, therefore, its range is limited. The extreme red ray, which is emitted by a substance just becoming red hot at a temperature of 1026° Fahr., and which is the least refrangible that can affect the eye, is caused by vibrations that are exactly half as frequent as the extreme violet ray emitted by the sun. It is important, in the explanations we are giving, to understand that, in a perfect solar spectrum, the distribution of the colored spaces is totally different from what it is in the case of the prismatic. In such a spectrum, as produced by the interference of rays passing through a surface of glass on which have been ruled with a point of a diamond parallel lines the $\frac{1}{10000}$ of an inch apart, the yellow occupies the middle region, and from this the light grades off, terminating at equal distances with the extreme red on one side and the extreme violet on the other. The circumstances of such an experiment prove that, the wave length for the red light being compared with that for the yellow, and also for that of the violet, they bear to one another the extraordinary and simple relation of 1, 1½, 2, establishing the assertion just made, that the extreme limit of perception of the eye is comprised in a single octave.

The heat of the colored rays is in proportion to their illuminating power.

I may refer to the experiments published by myself on this point, and also to those both antecedently and subsequently published by M. Melloni, in proof of the unreliability of the method of examining the solar spectrum by the prism in the manner introduced by Newton. More particularly to the discussion now before us does this remark apply; for the prism, as may be gathered from what has just been said, spreads out the colors of light unduly, and gives false indications respecting the distribution of heat. There can now remain no doubt, although the prism indicates the contrary, that the yellow, or brightest ray of light, is the hottest, and that the warming power of the others, orange, green, &c., follows in the order of their luminous intensity. When we have finished a description of the nervous mechanism of the eye, we shall find that the explanation of its function turns on the admission of this fact.

Limit in the comparison of the brightness of lights.

The eye is limited in another respect; it can not simultaneously compare lights which differ from one another in brilliancy if the one should be upward of 64 times as bright as the other. The more luminous overpowers or extinguishes the feebler. We can not see the light of a candle if we hold it up against the sun. I may again refer to the experiments I have published, establishing that upon this fact is founded the most exact method of photometry yet known.

2d. *Of the Nervous Mechanism of the Eye.*

In the preceding description it was stated that the retina, commonly

described as an expansion of the optic nerve, intervenes between the vitreous humor and the choroid coat.

Regarding it as composed of distinct layers, the innermost of which, in contact with the hyaloid membrane, is called the fibrous gray layer, arises from the tubules of the optic nerve, which have cast off the white substance of Schwann; and in passing, we may dwell emphatically upon the point that at that spot, where it exists alone, that is to say, where the optic nerve is entering the eye, vision can not be performed. Beneath, or outside this fibrous layer, comes the gray vesicular layer: it is analogous to the vesicular matter of the brain. The two layers thus far described are served with capillary blood-vessels of extreme minuteness. Outside of the gray vesicular layer is the granular layer, which, as its name imports, consists of a congeries of granules, which are probably the origin of the vesicles, new ones arising from this layer continually. Yet again, outside of the granular layer, comes a delicate sheet, known as the membrane of Jacob, but which is formed, in reality, from the juxtaposition of a set of rod-shaped and conical bodies, the thicker ends of the rods being outward, the thinner inward.

Construction of the retina and Jacob's membrane.

Fig. 202.

Membrane of Jacob.

Fig. 202 shows the partial detachment of the membrane of Jacob from the exterior of the retina. The membrane appears as delicate shreds, and may be advantageously demonstrated after the removal of the choroid, the specimen being placed under water.

In the preceding description I have followed the course usually taken by former anatomists, who describe the retina as consisting of successive layers or strata, but much more philosophical views are obtained by considering it in the manner introduced by H. Müller, that is to say, in its radial section. From this it appears that the four strata above mentioned, viz., 1. Jacob's layer of rods and cones; 2. The granular layer; 3. The vesicular layer; 4. The fibres of the optic nerve, are, in reality, all connected in such a way that, passing in a radial direction as respects the globe of the eye, all these different elements are successively combined, constituting what is termed the radiated fibre system. Thus from each of the proper fibres of the optic nerve a thread-like body passes radially through the thickness of the retina, including in its outward passage a vesicle, and again, beyond that, a granule, and, still farther, a cone, and terminating in a rod; so that from the extremity of the rod there is a continuous communication *through the* thickness of the retina to the fibres of the optic nerve; the

Perpendicular examination of the retina.

Radial fibre system.

rods are therefore to be regarded as the termination of the optic fibres. In the opinion of Müller and Kolliker, the rods and cones composing Jacob's membrane are the true percipients of light, communicating their condition to the fibres of the optic nerve by means of the connection which they thus maintain with it; or, perhaps, the rods and cones are conductors of the luminous impressions to the nerve-cells of the retina, which constitute a ganglion capable of perceiving light, and the fibres of the optic nerve merely communicate those impressions to the sensorium.

Whichever of these descriptions we may follow, the physiological fact which I desire to present with emphasis still remains the same. It is, that the sentient or receiving part of the retina is the posterior, that which is in contact with the black pigment.

The optic nerves: their chiasm and passage to the brain.

The second pair of nerves, from which the retina is thus derived, are, from their function, designated the optic nerves. They do not enter the sclerotic in its optical axis, but at a little distance on one side, and obliquely—a provision doubtless intended, in a measure, to avoid the occurrence of the blind spot on the centre of the field of vision, and to place it unsymmetrically in the two eyes, so that each eye shall compensate the defect of the other. The nerves from each eye converge to their chiasm, which is a commissure consisting of three distinct systems of tubules—an anterior set, which are commissures between the two retinæ, a posterior set, commissures between the two optic thalami, and an interior set, the proper tubules of the optic nerve, which cross, those from the right eye going to the left side of the brain, and those from the left eye going to the right side of the brain. The chiasm is therefore to be regarded as a complex structure, its posterior region being independent of the other parts, and existing in animals in which the optic nerve is not found, as, for example, in the mole.

Nerves to the eye-ball and annexed parts.

Besides the optic nerve, which is exclusively the nerve of vision, the collateral parts of the eye are supplied from various sources. The third pair, or motores-oculorum, supply the superior, inferior, and internal recti muscles, the inferior oblique, and the levator palpebræ. The fourth pair, or pathetici, supply the superior oblique or trochlear muscles. Of the fifth pair, supplies are derived from the frontal branch, lachrymal, the ciliary, and the infra-trochlear. The sixth pair, or abducent, pass to the external recti: supplies are also derived from the sympathetic. Of these nerves, the functions are very various; some are for the movement of the ball, or for general sensibility of the surface, or for the movements of the eyelids, or for those of the iris, and some for the lachrymal apparatus.

Of the Function of the Nervous Mechanism of the Eye.

The reasons have already been given for considering that it is the black pigment which acts as the receiving or optical screen, and not the retina. If no other argument was adduced for departing from the opinion usually expressed, which attributes this function to the retina, the thickness of that structure would be sufficient; images can only form with precision or sharpness upon an abrupt surface. And since it is now indisputably ascertained that both the chemical effect and the heating effect of the rays of light depend upon their absorption, those effects being in direct proportion to the completeness with which absorption is taking place, we are justified in inferring that, since the eye is sensible to rays of so low a degree of intensity, and to each of the colored ones equally, its screen of reception must not only be a superficies, but likewise a black one. Such a surface the black pigment is. In the case of albinos, and animals in which the black pigment is imperfectly developed, the receiving surface or screen is still the interior of the choroid. Under such circumstances, vision must be indistinct.

The black pigment, and not the retina, is the receiving screen.

Recalling what has been said respecting the diffuse sensibility of the lower members of the animal series to light, and the structure of ocelli, it accords well therewith to consider that the primary effect of the rays of light upon the black pigment is to raise its temperature, and this to a degree which is in relation to their intensity and intrinsic color; light which is of a yellow tint exerting, as has been said, the most energetic action, and rays which correspond to the extreme red and the extreme violet the feeblest. The varied images of external objects which are thus painted upon the black pigment raise its temperature in becoming extinguished, and that in the order of their brilliancy and color; the pigment thus discharging a double duty, as a surface of extreme sensibility for calorific impressions, and also as darkening the interior of the globe.

Heating effect on the pigment.

In this local disturbance of temperature, in my opinion, the act of vision commences, this doctrine being in perfect harmony with the anatomical structure of the retina, the posterior surface of which is its sensory surface, and not the anterior, as it ought to be if the explanation usually given of the nature of vision is correct; and therefore, as when we pass the tip of the finger over the surfaces of bodies, and recognize warm and cold spaces thereupon, the same occurs with infinitely more delicacy in the eye. The club-shaped particles of Jacob's membrane are truly tactile organs, which communicate to the sensory surface of the retina the condition of *temperature* of the black pigment.

Manner of perception by the retina.

But this communication of a variation of temperature implies a variation in the waste and repair of the retina itself, for there can be no doubt that all such changes are accelerated by an increase of heat, and diminished by its decrease. And though in this manner the origin of the action which has been set up is calorific, and therefore physical, it immediately becomes converted into a physiological equivalent in the metamorphosis and destruction of a nervous tissue.

The eye can not perceive rays which come from a luminous source the temperature of which is lower than 1000° F., for such rays can not pass through a stratum of water or through the humors of the eye. Natural philosophers, in making a distinction between light and heat, have too often overlooked the fact that, though thermometers are sensitive to rays of every sort, the eye is not. Its indications are complicated by the necessary introduction of absorbent media, which stop all rays the refrangibility of which is low.

Photographic effects are effects of a high temperature.

Many years ago, Count Rumford, from a limited examination of cases, concluded that all photographic effects are the effects of a high temperature. From an examination, continued for many years, of numerous phenomena of the same class, which have since been described, I have come to the same conclusion. The impinging of a ray of light on a point raises the temperature of that point to the same degree as that possessed by the source from which the ray comes, but an immediate descent takes place through conduction to the neighboring particles. This conducted heat, by reason of its indefinitely lower intensity, ceases to have any chemical effect, and hence photographic images are perfectly sharp on their edges. It may be demonstrated that the same thing takes place in vision, and in this respect it might almost be said that vision is a photographic effect, the receiving surface being a mathematical superficies, acting under the preceding condition. All objects will therefore be definite, and sharply defined upon it, nor can there be any thing like a lateral spreading. If vision took place in the retina as a receiving medium, all objects would be nebulous on the edges. This sharpness and grading off are happily illustrated by the metal daguerreotype and paper photograph respectively.

Absorption necessary for photographic action.

Perhaps it might be thought that the sharpness of impressions upon collodion or albumen stands in opposition to what is here said respecting the inefficiency of translucent media. Those substances, however, would be totally inert unless there had been purposely mingled with them some compound of easy decomposibility, capable of absorbing the blue rays, which are in these cases the effective photographic ones. Such a compound must commonly be of a yellow color. In these substances the absorption takes place with energy the moment the light has entered their surface. In the Philosoph-

ical Magazine, September, 1840, I have given proofs that the essential condition of the chemical activity of a ray of light is its being thus absorbed. As an illustration may be given the well-known result, that if chlorine and hydrogen be exposed to the sun, they unite with a violent explosion, but, under the same circumstances, oxygen and hydrogen will utterly refuse to unite, no matter how long the period of exposure may be, nor what the brilliancy of the light; and the difference in the two cases is merely this, that the chlorine, being of a yellowish color, can absorb the violet light, and therefore be influenced by it; but the oxygen, being uncolored, can not. For photographic effects, as well as calorific, the essential condition is absorption. A medium like the retina, which is without absorbing action, permits rays to pass through it without any kind of effect, but a surface like the black pigment, which receives them all equally, whatever their color may be, and absorbs them all equally, is equally affected by them all.

Function of the two chief layers of the retina and the choroid.

The impression arising from the disturbed condition of the retinal vesicles is carried by the optic tubules to the chiasm of the two nerves. Apart from the general facts elsewhere presented by physiology, the existence of a blind spot at the entrance of the optic nerve, where there is a necessary absence of vesicular structure, is a clear proof of the insensibility of the tubular structure to the influence of light. Considering, therefore, the retina as typically composed of three layers, one of tubules, one of vesicles, and one of granules, and these in health being perfectly transparent, the luminous beams pass through them just as they do through the atmosphere, without exerting the slightest effect; and as, when those rays strike the opaque surface of the earth, or are absorbed by the sea, heat is disengaged and effects ensue, so likewise, when they have reached the black pigment, the changes I have been designating arise. The vesicular layer undergoes rapid metamorphosis, the effect of that change is transmitted by the tubular layer, and in the granular the germs are constantly arising from which the waste of the middle layer is repaired. So, therefore, the tubular layer is for conduction, the vesicular layer for waste, the granular layer for repair; and now appears the significance of the construction and proximity of the choroid coat, for the waste of the vesicular layer can not occur save under the oxidizing influence of the arterial blood, nor can the nutrition of the granular layer be accomplished except under the same condition. Moreover, the resulting products of waste require to be quickly removed, and it is not possible to conceive the construction of an arrangement better adapted for this triple object than that which the choroid presents. On the old view of the nature of vision, the construction of the choroid seems to be without significance.

The analogy between the mechanism of the retina and that of the

skin, so far as waste and restoration are concerned, can not fail to be noticed.

The effect which has thus been communicated to the vesicular layer of the retina, through the intervention of Jacob's rods and cones, is now carried along the nervous tubules out of the globe of the eye. The nerves from each eye, converging, encounter one another at the chiasm, the triple structure of which has already been described. Here it is, however, to be understood that, while the proper optic tubules of the right eye go to the left brain, and of the left eye to the right brain, the anterior band of commissural tubules brings the two eyes into a special relation with one another, the right side of one eye corresponding with the right of the other, and the left with the left; or, to put the same statement under a more simple yet more instructive form, the outer side of one eye corresponds with the inner of the other, and in this manner the two retinæ become as if they were virtually incased the one within the shell of the other, an arrangement which obviously, as has been already remarked, compensates in a degree for the blind spot of each eye, and, indeed, eliminates the effect of all accidental irregularities, for numberless such irregularities must exist, there being a necessity, for example, that blood-vessels should cross through the sensitive to the conducting structures, and such blood-vessels give rise to lines of inertness.

Interconnection of the right and left eye.

From this commissural arrangement it comes to pass that each retina possesses regions of symmetry with the other, and on this singleness of vision depends; each point of the outer portion of the retina of the right eye has its point of symmetry in an inner portion of the left, and when from a distant object rays fall on these symmetrical points, that object will be seen single; but if, by the pressure of the finger or otherwise, we compel the image to fall in one of the eyes upon another, and, therefore, non-symmetrical point, the object at once becomes double. It should be remarked that this exchange of symmetry concerns only the lateral divisions, for the upper portion of one eye corresponds with the upper portion of the other, and the lower with the lower.

Single and double vision.

If the view which I have presented respecting the scalæ of the labyrinth of the ear be correct, that singular structure finds its equivalent in the black pigment of the eye; for though we only know in an indistinct manner the physical condition of black opacity, we may be certain that it arises from total interference of rays, and such, it is presumed, is the office of the scalæ of the ear.

Analogy between the scalæ and pigment.

Impressions made upon the retina do not disappear instantly, but gradually fade away, and in so doing occupy a certain period of time, which varies with the brightness of the original light, the existing condition of the eye, and the illumination to which it

Duration of impressions on the eye.

is exposed. This duration of impressions is commonly estimated at about one third of a second. It is a phenomenon analogous to that of the continuance of sound in the ear, and subserves an important purpose of keeping vision continuous and distinct during the winking of the eyelids. Commonly it is illustrated by referring to the familiar experiment of a stick lighted at one end and twirled rapidly round, which gives rise to the appearance of a continuous fiery circle. Many ingenious and interesting toys, such as the thaumatrope or wonder-turner, act on this principle.

Ocular spectra and complementary colors.

When the eye, particularly after a period of repose, as when we first wake in the morning, is turned to the window or some bright light, and then closed, a spectral impression is for a long time presented to the mind. If, instead of closing the eyes after looking at a bright light, they are directed to some white surface, a dark spectral appearance of the luminous object is seen. The explanation of this is evidently that those parts of the retina which have just undergone change are less fit to be acted upon by the more moderate light to which they are now exposed than those which have hitherto been unaffected. Under similar circumstances arise what are termed complementary colors. Thus, if we intently regard a red wafer on which the sun-rays are brightly shining, and then turn our eyes away to a feebly illuminated white wall, a green spectre of the wafer will be seen; and so of other colors. The complementary tint is that color which, added to the original one, forms white light. The explanation of these colored spectra depends upon the principle just mentioned.

Erect vision.

There have been few optical problems more warmly contested than that of erect vision. The image at the bottom of the eye is inverted, but we see the object upright. Some have supposed that we really see things upside down, but have learned to correct the error by the sense of touch. Doubtless the true explanation is to be found in the anatomical construction of the eye. It should be borne in mind that there is a very wide difference between the image formed at the bottom of an eye as we look at it, and, if such an expression may be used, as the eye itself looks at it. We see it from behind, the retina sees it from the front. Or, to put the statement perhaps more clearly, it is one thing to look at the images on the ground glass of a camera obscura from behind the instrument, and another to see them, as it were, from the interior of the box. The two positions are upon the opposite sides of a vertical axis, round which we may consider that we have turned, and hence the lateral inversion is corrected. That portion of the image which, seen from behind, was on the right of the spectator, is on his left if seen in front. A similar event must ensue in the case of the retina. As we have seen, it is its posterior face, looking at the black *pigment*, which is its sensitive surface. It sees, as it were, looking back-

ward, but not forward, and hence there arises a correction for the lateral inversion. This, of course, implies the existence of some structural arrangement which shall either correspondingly correct the vertical inversion, or bring back the lateral to its original erroneous state, and thereby establish a harmony of position in the two directions; and if, in the retina itself, the means exist for the correction of inversion, vertical as well as lateral, by changing the direction of the conducting tubules, it necessarily must be that that place of correction is where the retina is intersected by the optical axis of the eye. I think it is to be greatly regretted that we are not better acquainted with the construction of the yellow spot of Soemmering, which occurs at this very point. The ridge-like form it presents, the thin, uncolored spot in its centre, its more definite occurrence in those animals, as man, the quadrumana, and some saurians, the axes of whose eyes are nearly parallel to one another, seem to indicate, in a very significant manner, that at this place the correction in question is made. There are many ways in which we may conceive this to be done by varying the direction of the nervous tubules. As an illustration, it may be remarked that if, through a small hole made in a sheet of paper, a number of threads, the end of each of which is fastened to the back of the sheet, be caused to pass, under the condition that they do not cross one another in the hole, but leave its aperture open, their direction in space as they retire from the hole will be inverted as respects the direction in which they approached to it. The analogy between such an aperture and the foramen of Soemmering is too striking to be overlooked.

Lateral inversion corrected by the retina.

Suggestion respecting the yellow spot of Soemmering.

The stereoscope, invented by Professor Wheatstone, shows to what an extent our ideas of the solidity of objects depend on the differences of the images in each eye. By reason of their difference of position, each of the two eyes will have a different picture upon its black pigment of any solid object, and the mind, combining these dissimilar pictures into one, gathers therefrom the idea of solidity. If thus we offer to the eyes two pictures of a given object, presenting the same form as that object would have done when seen from each eye respectively, the mind combines these flat pictures together, and can not divest itself of the idea of a solid body. This is the principle of the stereoscope. It is shown by this instrument that, when two such pictures of different sizes are used, the mind combines them into one of intermediate magnitude. Probably this effect is involved in the circumstance that, when we look at an object unequally distant from the two eyes, we still see it single. When two images of different colors are employed, the mind can not combine them, but sees first the one and then the other, the brightest one continuing the longest.

The stereoscope.

The eye is adjusted to the varying intensities of light by the motions of the iris, which admits more or fewer rays according to its state of contraction, an action which, on certain occasions, is aided by the orbicularis palpebrarum, which, by bringing the eyelids together, limits the number of rays passing to the pupil. In man, the muscular fibres of the iris are of the unstriped form; in birds they are striped. Our perceptions of the intensities of light, as gathered from the state of the iris, can never be so distinct as the indications for sound yielded by the tensor tympani and stapedius muscles. In birds, however, it is probably different. We gather, to a great extent, our notion of the brilliancy of light from the rapidity of structural change taking place in the retina itself.

Adjustment to variations of brightness.

Although many images may be simultaneously existing upon the retina, the mind possesses the power of singling any one of them out and fastening attention upon it, just as among a number of musical instruments simultaneously played, one, and that perhaps the feeblest, may be selected, and its notes exclusively followed. These phenomena, however, are not dependent upon any peculiarity of construction of any of the organs of sense; and as the mind can perceive the images of external things, so can it give rise to spectral illusions which may simulate perfectly the aspect of external forms. The anecdotes of such occurrences which are to be found among all people are not the fabrications commonly supposed. The mind can be readily deceived, even in spite of itself, as the phenomena of the stereoscope prove; and spectres, having their origin in natural or diseased conditions of the brain, may accurately replace images that have been painted in the eye. It is said, however, that we may readily distinguish, by means of a simple optical test, a true external apparition, if any exists, from a phantom of diseased imagination; for by pressing duly with the finger on the ball of one of the eyes, external objects are at once doubled, but it is not so with a mental illusion; and we may therefore suspect that, even in the best authenticated cases of the appearances of these unnatural forms, had this test been applied, their true character would have been ascertained; and that, since none of them would have undergone duplication, they would at once have been detected as mere hallucinations of the mind.

Concentration of attention on one image.

Subjective images, and test for them.

The explanation of the function of vision which I have given on the preceding pages might be termed the calorific hypothesis, since it rests essentially on the fact that the temperature of the receiving screen of the eye is raised by the impinging of light upon it. The result thus far is of a purely physical nature, but it becomes physiological when we farther admit that changes of constitution ensue in the vesicular structure of the *retina*. These changes are rendered more rapid as the temperature is

r. It remains now to add that this is only one manner of looking thing. According as our hypothesis of the nature of light, of its ons to heat, and of its manner of establishing chemical changes may e special explanations we give of the functions of the eye will differ; ere is such a relationship among these hypotheses that n, without any difficulty, convert an explanation derived one into an explanation derived from another. It re- omes to little more than a translation of phraseology. e found the calorific hypothesis convenient, because we are led to it e comparative anatomy of the eye in starting from the ocelli of the forms; yet, with almost equal convenience, the function might have treated otherwise, viewing light as arising from ethereal undulations, dditional advantage then being obtained of establishing a parallel- etween the action of the organ of sight and that of hearing. Or, e manner, the case might have been viewed in its purely chemical t, photographically, as it might be said, the destruction of the vesic- tructure of the retina through the agency of arterial oxygen being as the primary physical act. But this, again, amounts only to a nt mode of stating the same effect, since, as I have shown (London dinburgh Philosophical Magazine, May, 1851), all chemical changes plished in material substances are occasioned by the establishment ratory motions therein, and Ampère has already demonstrated that phenomena of heat may be explained upon the doctrine of the vi- ns of the constituent molecules of bodies.

Translation of the calorific hypothesis to other forms of expression.

esting ourselves, therefore, of any farther concern in making a se- among the various hypotheses, we have adopted the view that the e of the retina originates in a calorific disturbance, because it ap- to be somewhat more convenient for our use.

s to be understood that the sensation of light is, however, purely l, and whatever can disturb the nutrition or waste of tina will give rise to luminous impressions. The press- the finger on the ball of the eye, a blow, the passage electric current, and divers other causes, will at once produce the rance of light, and even of colors. Heat is only one out of a mul- of agents that can disturb the retina.

The sensation of light purely mental.

3d. *Of the Accessory Apparatus of the Eye.*

e accessory apparatus of the eye consists chiefly of the eyebrows, elids, the Meibomian glands, the lachrymal mechanism, and the es for the movement of the ball.

e eyebrows are two arches of integument, covered with hair, on the edge of the orbit. They are usually classed with the dages of the eye upon the supposition that they protect

The eyebrows and eyelids.

that organ from undue intensity of light, or preserve it from the ingress of drops of sweat. They aid greatly in the expression of mental emotions, but perhaps should rather be looked upon as among the remaining vestiges of the hairy tegument which affords a protection to the entire skin of other mammals below man in the animal series. The eyelids may be described as a pair of valves, the upper one having a much greater latitude of motion than the lower. Their use is to afford protection to the eye by closing entirely over it, more particularly during sleep; to keep its optical surface moist and free from dust by their winking motion. They are brought into action by the contact of air or of irritating particles, through the fibres of the fifth and facial nerves, or by the agency of light upon the retina. The edges of the lids are furnished with rows of curved hairs, the eyelashes, which add greatly to the protection of the delicate organ beneath, while permitting vision to take place to a certain extent. Opening upon the edges of the eyelids are the foramina of the Meibomian glands, in the upper lid there being about thirty, in the lower somewhat fewer. The glands themselves are imbedded on the internal surface of the cartilage of the lids, and afford an oily secretion, which discharges the double duty of preventing adhesion of the lids, and, by its relation of capillary attraction, hindering the overflow of the water which moistens the eye upon the cheek.

The lachrymal apparatus.

Of the lachrymal apparatus, it may be said that in the same manner that we breathe upon a spectacle glass and wipe it that its surface may be perfectly clean, so it is necessary for the optical action of the cornea that its surface should be constantly washed, and even more so, for its lamellated structure is such that, if it be not kept constantly damp, it loses much of its transparency. This therefore renders it necessary that there should be a mechanism for the supply of water, another for spreading that water uniformly over the surface of the cornea, and a waste-pipe for carrying any surplus away. The lachrymal gland discharges the first of these duties. It is situated in the upper and outer angle of the orbit; its secretion, which is a bitter and somewhat saline water, is brought to the surface of the conjunctiva by eight or ten little ducts arranged in a row for the purpose of equalizing their discharge. The spreading of this fluid over the eye, and the simultaneous wiping of the surface, is accomplished by the eyelids. Usually the water that has been employed is dissipated by evaporation into the air; but if, by reason of meteorological circumstances, such as the dampness of the atmosphere, or by the supply being too abundant, there should arise an excess, it is carried off through two minute orifices which are upon the edge of the eyelids, the puncta lachrymalia. These draw off any collection of water that may have accumulated in the lachrymal lake, and, carrying it into the lachrymal sac, discharge it through the nasal duct into the

cavity of the nose. From this it is removed by evaporation, the current of air alternately introduced and expired affording the means of accomplishing that object in a remarkable manner. But should the secretion of water from the lachrymal gland become excessive, as in weeping, this draining mechanism is insufficient, and the water is discharged as tears down the cheek.

Of the muscles for the movement of the eye, the description has, in part, been given under that of the nerves. It may, however, be here remarked that the eyeball is moved by six muscles, the four straight and the two oblique. The straight muscles arise at the optic foramen, and are inserted into the sclerotic in the four quadrantal positions above, below, right, and left. The action of each of these muscles is to turn the eyeball toward itself; when they contract all together, they fix it. The superior oblique muscle arises from the same place, passes through a pulley beneath the internal angular process of the frontal bone, its tendon being inserted into the sclerotic near to the entrance of the optic nerve. The inferior oblique rises from the inner margin of the superior maxillary bone, passes beneath the inferior straight muscle, and is inserted into the sclerotic on its outer and posterior part, near the entrance of the optic nerve. The superior oblique rolls the globe inward and forward, the inferior rolls it outward and backward; acting together, they draw the globe forward and converge the axes of the eyes. The nervous supply for these various muscles has already been specified in page 334.

Motions of the eyeball.

CHAPTER XXI.

OF CEREBRAL SIGHT OR INVERSE VISION.

Difference between ordinary Vision and cerebral Sight.—Inverse Vision depends on the Vestiges of Impressions existing in the Brain.

Condition of our perceiving these Impressions is that they must be equal in Intensity to present Sensations.—Two Methods of accomplishing this Equalization: 1st, by re-enforcing the old Impressions; 2d, by diminishing the present Sensations.

Emergence of old Impressions in Sleep, Fever, Death.—Artificial Emergence of such Vestiges by Protoxide of Nitrogen, Opium, etc.

Cerebral Sight used teleologically to indicate the Immortality of the Soul.

The perception of external objects depends on the rays of light entering the eye, and converging so as to produce images which make an impression on the retina, and, through the optic nerve, are recognized by the brain. The direction of the influences, so far as the observer is concerned, is from without to within, from the object to the brain.

But the inverse of this is possible. Impressions already existing in the brain may take, as it were, an outward direction, and be projected or localized among external forms; or if the eyes be closed, or the observer is in darkness, they will fill up the empty space before him with scenery of their own.

Inverse vision depends primarily on the condition that former impressions, which are inclosed in the optic thalami or registering ganglia at the base of the brain, assume such a degree of relative intensity that they can arrest the attention of the mind. The moment that an equality is established between the intensity of these vestiges and sensations contemporaneously received from the outer world, or that the latter are wholly extinguished, as in sleep, inverse vision occurs, presenting itself, as the conditions may vary, under different forms, apparitions, visions, dreams.

From the moral effect to which these give rise, we are very liable to regard them as connected with the supernatural. In truth, however, they are the natural result of the action of the nervous mechanism, which of necessity produces them whenever it is placed, either by normal, or morbid, or artificial causes, in the proper condition. It can act either directly, as in ordinary vision, or inversely, as in cerebral sight, and in this respect resembles those instruments which equally yield a musical note whether the air is blown through them or drawn in.

Difference between sleeping and waking illusions.

The hours of sleep constantly present us, in a state of perfect health, illusions which appear to address themselves to the eye rather than to any other sense, and these commonly combine into moving and acting sceneries, a dream being truly a drama of the night. In certain states, appearances of a like nature intrude themselves before us even in the open day, but these, being corrected by the realities with which they are surrounded, impress us very differently to the phantoms of our sleep. The want of unison between such images and the things among which they have intruded themselves, the anachronism of their advent, or other obvious incongruities, restrain the mind from delivering itself up to that absolute belief in their reality which so completely possesses us in our dreams. Yet, nevertheless, such is the constitution of man, the bravest and the wisest encounter these fictions of their own organization with awe.

Frequency of mental hallucinations.

If we measure the importance of events occurring to us by their frequency, the depth of the impression they make, the influence they exert on our own individual career, or have exerted on the progress of the whole human race, there are very few more deserving the discussions of physiology than visual hallucinations. With respect to frequency, it may be reasonably said that, *if images* arise in the mind by night as numerously as sensible forms

present themselves by day, it is not likely that they should be better borne in memory; but of the thousands of objects we encounter every day of our lives, how few there are that we can distinctly recollect at its close. We think we explain this wonderful forgetfulness by saying we have paid no attention to them; and, in like manner, the dreams we remember are perhaps only a very insignificant proportion of those which have been presented to the mind.

Their moral effect.

It has been said that a belief in apparitions is natural to every man. However much we may dissent from the correctness of such a general assertion, there can be no doubt that it has a foundation in truth. The faith of a child in this particular is only gradually sapped as he grows up to be a man. Nay, even in mature life there may always be found those who have an unwavering confidence in the reality of these illusions, and many of these are persons characterized by their moral courage and love of truth. I have just remarked that few things have exerted a greater influence on the career of the human race than a firm belief in these spiritual visitations. The visions of the Arabian prophet have ended in tincturing the daily life of half the people of Asia and Africa for a thousand years. A spectre that came into the camp at Sardis unnerved the heart of Brutus, and thereby put an end to the political system that had made the great republic the arbiter of the world. Another, that appeared to Constantine, strengthened his hand to the accomplishment of that most difficult of all the tasks of a statesman, the destruction of an ancient faith.

But these were all impostures, it may be said. Not so; they were no impostures of the persons to whom they are reported to have occurred, and who assuredly firmly believed in the real existence of what they thought they saw. To, the two or three instances mentioned above, scores of a like kind might be added, which have issued in the committing of men to the most earnest kind of work. So often do historians notice an element of this kind mingling in the career of those who have made the deepest mark on our race, that some are to be found who assert the necessity of such a condition to any widespread and permanent political event. Whatever we may think of such a conclusion, the premises on which it is founded are well worthy of our consideration. The physiologist is not at liberty to deny that lunatic and delirious men have faith in what they see. Their senses may deceive them, but they are not impostors. It is for him to consider how phantoms may arise in conditions of apparent health as well as in states of disease; in the tranquillity of the solitary man as well as in the feverish excitement of the enthusiast.

Visual hallucinations are of two kinds, those which are seen when the eyes are open, and those perceived when they are closed. To the for-

Apparitions and visions. mer, the designation of apparitions; to the latter, that of visions may be given. Dreams therefore come under the latter class.

The simplest form of apparition is that known among physicians as muscæ volitantes. These are dark specks, like flies, which seem to be floating in a devious course in the air. They are owing to disturbances or changes in the retina. They often appear to occupy the dying.

Muscæ volitantes.

Of visions the most common, because they can be voluntarily produced, are those which depend on the remains of impressions in the retina and optic centres. If, when we awake in the morning, our eyes are turned for a moment to a window or other bright object, and then closed, there still appears to the mind a spectral representation of the object, which gradually fades away. These illusions can be caused to have, as it were, a movement in the dark space before us, answering to the voluntary rotation of the eyeball. Sometimes, when the light is not sufficiently intense, or the nervous organs not sensitive enough, the vision does not make its appearance on the closing of the eyelids, but, after fastening the attention on the position in which it is expected to come, it slowly emerges at last. That it consists in a real impression which has been made on those organs, and is not a mere product of the unaided imagination, is very clear from the fact that we may discern, by attentively considering it, many little peculiarities which we have not had time to notice in the original object; thus, if there has been a lace curtain, or other such well-marked body before us, we can not only see in the vision the places where its folds intersect the windows, but likewise, if the impression be a good one, all the peculiarities of its figured pattern; and that our conclusions in these respects are correct is proved as soon as we re-open our eyes.

Remains of optic impressions.

Seat of apparitions and visions.

Between apparitions and visions is an intermediate class, of which it is not my object now to say much; they may, however, be styled deceptions. These take their origin in some outward existing reality, and are exaggerations of the fancy. They are commonly encountered in the evening twilight, or in places feebly illuminated. Sir W. Scott says of children that lying is natural to them, and that to tell the truth is an acquired habit. If they are thus by nature prone to deceive those around them, they are none the less prone to deceive themselves. To them, a white object, faintly descried in the obscurity, is easily expanded into a moving and supernatural thing.

Deceptions.

In a physiological sense I consider that simple apparitions arise from disturbances or disease of the retina; visions from the traces of impressions inclosed at a former time in the corpora quadrigemina and op-

tic thalami. In their most highly-marked state the former may be treated of as results of insanity of the retina, the latter as of cerebral vision.

Disturbance of the retina, brought on by any cause whatever, may give rise to simple spectral apparitions, which, as the circumstances change, will have an indefinite contour or a definite form; nor are they merely shades and shadows: they may be presented in colors, which, however, are usually dim or subdued. Thus, if, the eyelids being closed, we press gently with the tip of the finger on the inner or outer angle of one of the eyes, a gray spot surrounded by colors makes its appearance on the opposite side of the same eye, and dances about as the pressure of the finger varies. With a more extensive and heavier pressure clouds of various rainbow tints fill up all the imaginary space before us. In like manner, the passage of an electric current from a voltaic pair induces a flash of light of considerable brilliancy. Internal pressures and spontaneous variations in the rate of metamorphosis and nutrition of the retina act in a manner analogous to external disturbances.

Apparitions from retinal disturbance.

From the muscæ volitantes, which may be regarded as the first rudiments of apparitions, it is but a step to the intercalation of simple or even grotesque images among the real objects at which we are looking; and, indeed, this is the manner in which they always offer themselves, as resting or moving among the actually existing things. I do not undertake to say how far we are liable to practice deception upon ourselves, after the manner we have spoken of in children, when we have once detected the fact that we are liable to this infirmity. An inanimate object—for instance, a stick—is seen upon the floor; we go to take it up; we find there is nothing there; we return to our first position, but we can observe no shadow or other reality that can be offered as an explanation of what we have seen. An event of this kind predisposes us, perhaps, to return to that disposition of exaggeration so natural to our early life, and the next time the retina deceives us we involuntarily give to the hallucination motion and a more definite form.

Insects flying in the air, or, rather, floating in vacancy before us, present the incipient form of retinal malady. It may be provoked by undue use of the eyes, as reading by lamp-light. I remark it constantly, in my own case, after prolonged use of the microscope. In a more aggravated form, it less frequently occurs as producing stars or sparks of light. From the earliest times, physicians have observed that it is a "bad sign" when the patient localizes these images. "If the sick man says there be little holes in the curtains, or black spots on his bedclothes, then is it plain that his end is at hand."

Under the title of pseudoblepsis, or false vision, medical authors enumerate several varieties of the foregoing phenomena; but when, as is

Co-existence of retinal insanity and cerebral sight.

most commonly the case, the derangement which gives origin to these appearances is not limited to the retina, but, arising in some constitutional affection, involves more or less completely the entire nervous apparatus of the eye, retinal insanity and cerebral vision occur together. In those cases which have been investigated in a philosophical manner by the patients themselves, this complication is often distinctly recognized. Thus Nicolai, the Prussian bookseller, who published in the Memoirs of the Royal Academy of Berlin an interesting account of his own sufferings, states that, of the apparitions of men and women with which he was troubled, there were some which disappeared on shutting the eyes, but some did not. In such a case there can be no doubt that the disease affected the corpora quadrigemina and the optic thalami as well as the retina.

This condition, in which the receiving centres and registering ganglia at the base of the brain are engaged, is the one which yields the most striking instances of hallucinations in which apparitions and visions coexist. It can, like the less complicated forms, be brought on artificially, as in the delirium tremens which follows a cessation from the customary use of alcohol, or in the exaltation by the purposed administration of opium or other drugs. In this, as in those forms, it is the localization of the phantom among the bodies and things around us that begins to give power to the illusion. The form of a cloud no bigger than the hand is perhaps first seen floating over the carpet, but this, as the eye follows it, takes on a sharp contour and definite shape, and the sufferer sees with dismay a moping raven on some of the more distant articles of furniture. Or, out of an indistinct cloud, faces, sometimes of surprising loveliness, emerge, one face succeeding as another dies away. The mind, ever ready to practice imposture upon itself, will at last accompany the illusion with grotesque or even dreadful inventions. A sarcophagus, painted after the manner of the Egyptians, distresses the visionary with the rolling of its eyes. Martin Luther thus more than once saw the devil under the well-known form popularly assigned to him in the Middle Ages.

Brought on artificially by alcohol, opium, &c.

As the nervous centres have been more profoundly involved, these visions become more impressive. Instead of a solitary phantom intruding itself among recognized realities, as the shade of a deceased friend opens the door and noiselessly steps in, the complicated scenes of a true drama are displayed. The brain becomes, as it were, a theatre. According as the travel or the reading of the sick man may have been, the illusion takes a style: black vistas of Oriental architecture, that stretch away into infinite night; temples, and fanes, and the battlemented walls of cities; colossal Pharaohs, *sitting* in everlasting silence, with their hands upon their knees. "I

Visions of false or exaggerated scenery.

saw," says De Quincey, in his Confessions of an Opium-eater, "as I lay awake in bed, vast processions, that passed along in mournful pomp; friezes of never-ending stories, that to my feelings were as sad and solemn as if they were stories drawn from times before Œdipus or Priam, before Tyre, before Memphis; and, at the same time, a corresponding change took place in my dreams; a theatre seemed suddenly opened and lighted up within my brain, which presented nightly spectacles of more than earthly splendor."

Apparitions are the result of a false interpretation of impressions contemporaneously made on the retina; visions are a presentment of the relics of old ones which yet remain in the registering ganglia of the brain. We convince ourselves of the truth of this general assertion not so well from an examination of one or more well-related or authenticated cases as from what may be termed the natural history of ghosts. The Greeks and Romans of antiquity were just as much liable to disorders of the nervous system as we are, but to them supernatural appearances came under mythologic forms, Venus, and Mars, and Minerva. The places of these were taken in the dreams of the ascetics of the Middle Ages by phantoms of the Virgin and of the saints. At a still later time, in Northern Europe, and even in England, where the old pagan superstitions are scarcely yet rooted out of the vulgar mind, even though the Reformation has broken the system of ecclesiastical thought, fairies, and brownies, and Robin Goodfellow survive. The form of phantoms has changed with change of the creeds of communities, and we may therefore, with good Reginald Scot, inquire, "If the apparitions which have been seen by true men and brave men in all ages of the world were real existences, what has become of the swarms of them in these latter times?"

Secular variations in the aspect and costume of spirits.

One class of apparitions—perhaps it was the first to exist, as it is the last to remain—has survived all these changes—survived them because it is connected with a thing that never varies—the affection of the human heart. To the people of every age the images of their dead have appeared. They are not infrequent even in our own times. It would be an ungracious task to enter on an examination of the best authenticated of such anecdotes. Inquiries of this kind can scarcely be freed from the liability to an imputation on personal veracity, perceptive power, or moral courage; and, after all, it is not necessary to entangle ourselves with these causes of offense. It is enough for us to perceive that even here incongruities may be pointed out. The Roman saw the shade of his friend clothed in the well-known toga; the European sees his in our own grotesque garb. The spirit of Maupertuis, which stood by the bay window of the library at Berlin, had on knee-breeches, silk stockings, and shoes with large silver buckles. To the philosopher it may

perhaps occur that it is very doubtful if, among the awful solemnities of the other world, the fashions ever vary. Let us pause before we carry the vanities of life beyond the grave.

From such reflections as the preceding, I think it may therefore be concluded that there are two sources from which spectral appearances are derived: 1st. Disturbance of the retina, which presents masses of light and shade or colors to the mind, and these are worked by the fancy into definite forms on the same principle that we figure to ourselves pictures of faces among glowing embers. This constitutes retinal insanity. 2d. Gradual emergence from the registering ganglia of the brain of old impressions, which are rendered as intense and distinct as contemporaneous sensations. The two forms may, however, coexist. Of the latter, I may observe that the views of Dr. Hibbert, in his work on Apparitions, appear to me to approach nearer to the truth than those of any other author. It will be perceived, however, after perusing his interesting book, that I have not laid the stress he has done on the mechanical influence of the circulation of the blood, but view the effect as of a more purely nervous kind.

As the emergence of old images which have been registered in the optic thalami is not only connected with the physiological explanations we have given of the functions of the brain, but also occurs under circumstances of such singularity as to border upon the supernatural, we may pursue the consideration of it a little farther. It may, I think, be broadly asserted that all spectral appearances refer to things that are past, persons who are dead, events which have taken place, scenes that we have visited; or, if we have not seen the actual reality, then pictures, statues, or other such representations thereof. It has never yet occurred that any one has seen a phantom the indications of the bodily presence or representation of which, until that moment, he had never known. Thus, in the Middle Ages, the spectres of African negroes were common enough, but no man ever witnessed one of an American Indian, yet these, in their turn, prevailed after the voyage of Columbus. They were no strangers to the early colonial settlers. The same may be said of all kinds of inanimate objects.

All spectral appearances refer to past events.

As illustrating the manner in which impressions of the past may emerge from the registering ganglia, I shall here furnish an instance which borders closely upon the supernatural, and fairly represents the most marvelous of these psychological phenomena. It occurred to a physician, who related it in my hearing to a circle whose conversation had turned on the subject of personal fear. "What you are saying," he remarked, "may be very true, but I can assure you that the sentiment of fear, in its utmost degree, is much less common than you suppose; and, though you *may* be surprised to hear me say it, I know from personal experience that

Illustration of the emergence of old impressions in a repetition of dreams.

this is certainly so. When I was five or six years old, I dreamed that I was passing by a large pond of water in a very solitary place. On the opposite side of it there stood a great tree, that looked as if it had been struck by lightning; and in the pond, at another part, an old fallen trunk, on one of the prone limbs of which there was a turtle sunning himself. On a sudden a wind arose, which forced me into the pond, and in my dying struggles to extricate myself from its green and slimy waters, I awoke, trembling with terror.

"About eight years subsequently, while recovering from a nearly fatal attack of scarlet fever, this dream presented itself to me, identical in all respects, again. Even up to this time I do not think I had ever seen a living tortoise or turtle, but I indistinctly remembered there was the picture of one in the first spelling-book that had been given me. Perhaps, on account of my critical condition, this second dream impressed me more dreadfully than the first.

"A dozen years more elapsed. I had become a physician, and was now actively pursuing my professional duties in one of the Southern states. It so fell out that one July afternoon I had to take a long and wearisome ride on horseback. It was Sunday, and extremely hot; the path was solitary, and not a house for miles. The forest had that intense silence which is so characteristic of this part of the day; all the wild animals and birds seemed to have gone to their retreats, to be rid of the heat of the sun. Suddenly, at one point of the road I came upon a great stagnant water-pool, and, casting my eyes across it, there stood a pine-tree blasted by lightning, and on a log that was nearly even with the surface, a turtle was basking in the sun. The dream of my infancy was upon me; the bridle fell from my hands; an unutterable fear overshadowed me as I slunk away from the accursed place.

"Though business occasionally afterward would have drawn me that way, I could not summon the resolution to go, and actually have taken roundabout paths. It seemed to me profoundly amazing that the dream that I had had should, after twenty years, be realized without respect to difference of scenery, or climate, or age. A good clergyman of my acquaintance took the opportunity of improving the circumstance to my spiritual advantage; and in his kind enthusiasm, for he knew that I had more than once been brought to the point of death by such fevers, interpreted my dream that I should die of marsh miasm.

"Most persons have doubtless observed that they suddenly encounter circumstances or events of a trivial nature in their course of life of which they have an indistinct recollection that they have dreamed before. It seemed for a long time to me that this was a case of that kind, and that it might be set down among the mysterious and unaccountable. How wonderful it is that we so often fail to see the simple explanation of

things, when that explanation is actually intruding itself before us. And so in this case; it was long before the truth gleamed in upon me, before my reasoning powers shook off the delusive impressions of my senses. But it occurred at last; for I said to myself, Is it more probable that such a mystery is true, or that I have dreamed for the third time that which I had already dreamed of twice before? Have I really seen the blasted tree and the sunning turtle? Are a weary ride of fifty miles, the noontide heat, the silence that could almost be felt, no provocatives to a dream? I have ridden under such circumstances many a mile, fast asleep, and have awoke and known it; and so I resolved that if ever circumstances carried me to those parts again, I would satisfy myself as to the matter.

"Accordingly, when, after a few years, an incident led me to travel there, I revisited the well-remembered scene. There still was the stagnant pool, but the blasted pine-tree was gone; and after I had pushed my horse through the marshy thicket as far as I could force him, and then dismounted, and pursued a close investigation on foot in every direction round the spot, I was clearly convinced that no pine-tree had ever grown there; not a stump, nor any token of its remains, could be seen; and so now I have concluded that, at the glimpse of the water, with the readiness of those who are falling asleep, I had adopted an external fact into a dream; that it had aroused the trains of thought which, in former years, had occupied me; and that, in fine, the mystery was all a delusion, and that I had been frightened with less than a shadow."

The instructive story of this physician teaches us how readily, and yet how impressively, the remains of old ideas may be recalled; how they may, as it were, be projected into the space beyond us, and take a position among existing realities. That such images arise from a physical impression, which has formerly been made in the registering ganglia, it is impossible to doubt, and that for their emergence from their dormant state it is necessary that there should be a dulling or blunting of contemporaneous sensations, so that these latent relics may present themselves with a relatively equal force. This equalization of the intensity of an old impression with a present sensation may be brought about in two different ways: 1st. By diminishing the force of present sensations, as when we are in a reverie, or have fallen asleep, or by breathing vapors unsuited for the support of respiration; 2d. By increasing the activity of those parts of the brain in which the old impressions are stored up. On each of these a few remarks may be made.

Equalization of old impressions and new sensations necessary for visions.

Modes of accomplishing that equalization.

Cerebral vision depends on an equalization in intensity between present sensations and old impressions. So long as the former predominate *in power*, the latter excite no attention or are wholly overlooked. This

condition is illustrated by such facts as that the flame of a candle, held against the sun, is utterly overpowered and imperceptible, but is seen of its proper brightness when it is in presence only of another flame like itself; or as the stars, which are concealed by day, are plain enough when the sun sets. Ancient impressions, harbored in the optic thalami, can not make themselves felt against sensations just establishing themselves; for as, when we have looked at a bright window and then closed our eyes, the retinal phantom we see becomes paler and paler, and after a while dies out, so do cerebral images undergo a diminution of intensity with lapse of time, though it may be questioned whether they ever entirely wear out. The law which obtains in our economy for other organs of sense applies in these cases too. Even in contemporaneously-occurring sensations, unless there is something like an equality between them, the weaker makes no impression upon us. In the presence of a bright light, a less brilliant one can not be seen; a feeble sound is made inaudible by an intensely loud one; minute variations of temperature become imperceptible when we are submitted to a great heat or cold. Ideas are no more than the vestiges of what were once sensations, and are subjected to the same physical law. For them to become embodied, and to cheat the mind into a belief of their re-existence, equivalent in all regards to outward and actually-existing things, the impressions of these latter must be diminished in their power, or the vigor of the former must be re-enforced.

Illustrations of impressions overpowering each other.

So, when we are passing away in sleep, the organs of sense no longer convey their special impressions with the clearness and force that they did in our waking hours, and this gives to the decaying traces which are stored in the registering ganglia the power of drawing upon themselves the attention of the mind.

Emergence of old impressions in sleep.

So, likewise, in the delirium of fevers, the spectral phantoms which trouble the sick are first seen when the apartment is darkened and kept silent, and especially when the patient closes his eyes. Until the senses are more completely overwhelmed, these shadows will disappear on brightly illuminating the room or on opening the eyes. And so, too, in the hour of death, when outer things are losing their force upon the dim eye, and dull ear, and worn-out body, images that have reference to the manner of our past life emerge; the innocent and good being attended in their solemn journey by visions in unison with their prior actions and thoughts, the evil with scenes of terror and despair; and it is right that it should be so.

Emergence of old impressions in the delirium of fevers and in the article of death.

The enfeebling of sensations which we are in the act of receiving from external sources, so as to bring them on an equality with those which have been long ago impressed, not only occurs in the condition

Emergence of old impressions by artificial means.

of sleep, and in the article of death, but may, in a temporary manner, be established by resorting to certain physical agents and drugs. Pressure upon the brain, either accidentally or purposely applied, is well known to produce such a result, and, in like manner, the inhalation of various agents, such as pure hydrogen gas, the vapor of ether or chloroform, or other non-supporters of respiration. On breathing these substances, anæsthesia is soon induced; the external world disappears; and, on carrying forward the operation to a due extent, the mind and the brain are literally left to themselves. Opium acts in like manner, more particularly in the case of those who have accustomed themselves to its undue use. It, however, not only blunts the force of new impressions, but exerts a positive agency in intensifying the decaying remains of old ones. Under its full influence, the true relations of space and of time disappear: a century of events is lived through in a single night; the vision can comprehend distances approaching to the infinite; and yet, under these circumstances, the mind does not perceive a riot of incongruous combinations, but every thing is presented in a methodical and orderly way—pictures, all the parts of which are in just proportions and severe keeping to each other, and long sequences of events which maintain a mutual harmony.

Artificially increased functional activity of the brain increases them.

But, as I have just remarked, the equalization of new sensations with old impressions, which is necessary for phantom appearances, and the incarnation and outward localization of ideas—that is, cerebral vision—may take place by heightening or re-enforcing the old impressions, as well as by diminishing the intensity of the new sensations; and as in the former case, so in this, the result can be reached in many different ways. Whatever will cause increased functional activity of the cerebral structure may recall these old images in force. It is almost unnecessary to allude to the delirium which attends inflammatory states of the brain. Artificial experiments are more instructive.

Case of protoxide of nitrogen.

For the purpose of increasing the functional activity of the cerebral structure, protoxide of nitrogen, by reason of its greater solubility in the blood, exceeds in power even oxygen gas itself. This substance, when respired, at once awakens long trains of vivid ideas, the recollection of all kinds of former scenes. Its action is divisible into two periods, the first corresponding to the heightened sensibility arising from the increased oxidation it is establishing in the economy, the second to the depression which soon comes on through the consequent accumulation of carbonic acid, and which the lungs and skin are unable with sufficient quickness to remove. Sir H. Davy, who first recognized its physiological power, has given us a graphic description of these effects. He says, "A thrilling, extending from the chest to the extremi-

ties, was almost immediately produced. I felt a sense of tangible extension, highly pleasurable, in every limb. My visible impressions were dazzling and apparently magnified. I heard distinctly every sound in the room, and was perfectly aware of my situation. By degrees, as the pleasurable sensation increased, I lost all connection with external things; trains of vivid visible images rapidly passed through my mind, and were connected with words in such a manner as to produce sensations perfectly novel. I existed in a world of newly-connected and newly-modified ideas. When I was awakened from this semi-delirious trance by Dr. Kinglake, who took the bag from my mouth, indignation and pride were the first feelings produced by the sight of the persons about me. My emotions were enthusiastic and sublime, and for a moment I walked round the room perfectly regardless of what was said to me. As I recovered my former state of mind, I felt an inclination to communicate the discoveries I had made during the experiment. I endeavored to recall the ideas; they were feeble and indistinct. One recollection of terms, however, presented itself, and with the most intense belief and prophetic manner I exclaimed to Dr. Kinglake, 'Nothing exists but thoughts; the universe is composed of impressions, ideas, pleasures, and pains.'"

In like manner, the intoxication that arises from alcohol has two distinct stages, depending on entirely different phases of its chemical action. At first there is an exaltation of effects, because of the increased functional activity established; but this, after a time, is succeeded by a dullness, or even stupefaction, attributable to the impression which the carbonic acid arising from the oxidation of the alcohol is making upon the nervous centres.

Two methods of equalization of old impressions and existing sensations.

By two different methods, therefore, ancient impressions may be equalized, as respects intensity, with new sensations. The vigor of the former may be increased, or the effect of the latter diminished.

Equalized in any way in their force, the mind is ready to confound its own ideas and external forms together. A cause which, perhaps, might seem to be trivial, fastens the attention, and at once a solitary form, or even the machinery of a long drama, emerges. It is no more possible for us to say why the thought runs in one course rather than another, and lays hold of image after image in succession, than we can foretell the way of a spark that moves darkling on the ashes of a piece of burned paper. Yet it too runs in connected lines.

No better evidence can be given that the images we are speaking of are impressions of past events registered in the brain, and which gain the power of drawing upon themselves the attention of the mind, either by their assuming an unwonted intensity, or by the diminution of the in-

Proof of the existence of impressions in the registering ganglia and their emergence.

fluence of newly-arriving sensations, than the philosophical observations which have been made by some of those who have been liable to these infirmities on their own cases. Thus, in such a case recorded in Nicholson's Philosophical Journal, and alluded to by Dr. Hibbert: "I had a visit," said the patient, "from Dr. C——, to whom, among other remarks, I observed that I then enjoyed the satisfaction of having cultivated my moral habits, and particularly in having always endeavored to avoid being the slave of fear. 'I think,' said I, 'that this is the breaking up of the system, and that it is now in progress to speedy destruction. In this state, when the senses have become confused, and no longer tell me the truth, they still present me with pleasing fictions, and my sufferings are mitigated by that calmness which allows me to find amusement in what are probably the concluding scenes of life.' I give these self-congratulations without scruple, more particularly because they led to an observation of fact which deserves notice. When the doctor left me, my relaxed attention turned to the phantasms, and some time afterward, instead of a pleasing face, a visage of extreme rage appeared, which presented a gun at me, and made me start; but it remained the usual time, and then gradually faded away. This immediately showed me the probability of some connection between my thoughts and these images, for I ascribed the angry phantasm to the general reflection I had formed in conversation with Dr. C——. I recollected some disquisitions of Locke, in his treatise on the Conduct of the Mind, where he endeavors to account for the appearance of faces to persons of nervous habits. It seemed to me as if faces in all their modifications, being so associated with our recollections of the affections of passions, would be most likely to offer themselves in delirium; but I now thought it probable that other objects could be seen, if previously meditated upon. With this motive it was that I reflected upon landscapes and scenes of architectural grandeur while the faces were flashing before me, and after a considerable interval of time, of which I can form no precise judgment, a rural scene of hills, valleys, and fields appeared before me, which was succeeded by another and another in ceaseless succession, the manner and times of their respective appearance, duration, and vanishing being not sensibly different from that of the faces. All the scenes were calm and still, without any strong light or glare, and delightfully calculated to inspire notions of retirement, of tranquillity, and happy meditation." The same writer adds in another place, "The figures returned, but now they consisted either of books, or parchments, or papers containing printed matter. I do not know whether I read any of them, but am at present inclined to think that they were not either distinctly legible, or did not remain a sufficient time before they vanished. I was now so well aware of the connection of thought

with their appearances, that, by fixing my mind on the consideration of manuscript instead of printed type, the paper appeared, after a time, only with manuscript writing; and afterward, by the same process, instead of being erect, they were all inverted, or appeared upside down."

External localization of phantasms.

We can not fail to remark the close resemblance between these illusions, arising from a fixed meditation on recollected scenery, and the phantoms which are witnessed after our gaze has been steadily directed to some brightly-illuminated object, as a window, when we first awake. In both there is the same subdued and uncertain brilliancy of effect; in both the same gradual fading away; in both the mind does not refer the image it contemplates to an inward point or place, but sets it forth outwardly, projecting it into the empty or occupied region beyond. In inverse as in ordinary vision, the law of the line of visible direction is enforced, and this reference of cerebral images to a definite point in outer space is a phenomenon of the same kind as the appearance of the invisible coin on pouring water into a basin, the lifting of ships into the air by atmospheric refraction, the appearance of the sun and moon every day above the horizon before they have actually risen and after they have set, and many other optical illusions that might be mentioned.

The nervous mechanism constructed to indicate the immortality of the soul.

Physiology, though full of teleological illustrations—that is, examples of the use of means for the accomplishment of an end—has none more worthy of our consideration than this of inverse vision. Men in every part of the world, even among nations the most abject and barbarous, have an abiding faith not only in the existence of a spirit that animates us, but also in its immortality. Of these there are multitudes who have been shut out from all communion with civilized countries, who have never been enlightened by revelation, and who are mentally incapable of reasoning out for themselves arguments in support of those great truths. Under such circumstances, it is not very likely that the uncertainties of tradition derived from remote ages could be any guide to them, for traditions soon disappear except they be connected with the wants of daily life. Can there be, in a philosophical view, any thing more interesting than the manner in which these defects have been provided for, by implanting in the very organization of every man the means of constantly admonishing him of these facts, of recalling them with an unexpected vividness before him, even after they have become so faint as almost to die out? Let him be as debased and benighted a savage as he may, shut out from all communion with races whom Providence has placed in happier circumstances, he has still the same organization, and is liable to the same physiological incidents as ourselves. Like us, he sees in his visions the fading forms of landscapes, which are, perhaps, connected with

some of his most grateful recollections; and what other conclusion can he possibly derive from these unreal pictures than that they are the foreshadowings of another land beyond that in which his lot is cast? Like us, he is visited at intervals by the resemblances of those whom he has loved or hated while they were alive; nor can he ever be so brutalized as not to discern in such manifestations suggestions which to him are incontrovertible proofs of the existence and immortality of the soul. Even in the most refined social conditions we are never able to shake off the impression of these occurrences, and are perpetually drawing from them the same conclusions as did our uncivilized ancestors. Our more elevated condition of life in no respect relieves us from the inevitable consequences of our own organization any more than it relieves us from infirmities and disease. In these respects, all over the globe, we are on an equality. Savage or civilized, we carry about within us a mechanism intended to present us with mementoes of the most solemn facts with which we can be concerned, and the voice of history tells us that it has ever been true to its design. It wants only moments of repose or of sickness, when the influence of external things is diminished, to come into full play, and these are precisely the moments when we are best prepared for the truths it is going to suggest. Such a mechanism is in keeping with the manner in which the course of nature is fulfilled, and bears in its very style the impress of invariability of action. It is no respecter of persons. It neither permits the haughtiest to be free from the monitions, nor leaves the humblest without the consolation of a knowledge of another life. Liable to no mischances, open to no opportunities of being tampered with by the designing or interested, requiring no extraneous human agency for its effect, but always present with each man, wherever he may go, it marvelously extracts from vestiges of the impressions of the past overwhelming proofs of the reality of the future, and, gathering its power from what would seem to be a most unlikely source, it insensibly leads us, no matter who or where we may be, to a profound belief in the immortal and imperishable, from phantoms which have scarcely made their appearance before they are ready to vanish away.

It is scarcely necessary for me to do more than barely refer to the assertions of those who would have it believed that they look upon all these appearances as fictions and deliberate impostures. What is to become of all history if such a doctrine could be maintained? Human evidence must be regarded as utterly worthless. Moreover, no one denies the existence of dreams, and the phenomena we have been here treating of are philosophically of the same order.

CHAPTER XXII.

OF TOUCH, AND THE DETERMINATION OF PRESSURES AND TEMPERATURES.

Functions of the tactile Mechanism: its Structure.—Regions of different Sensitiveness.—Comparative Physiology of Touch.—Estimate of physical Qualities.
Perception of Temperature.—Subjective Sensations of Temperature.

THE tactile organ is the skin, or some part, modification, or appendage of it. The general functions of the skin have been already described. It remains to speak of it in connection with the sense of touch.

Functions of the tactile mechanism.

An impression has long prevailed among physiologists that this sense should be considered as offering several subdivisions. Thus, for instance, we have a consciousness of the general condition of the muscular system—muscular sense, as it might be termed—and this, in some cases, is exquisitely perfect, as may be gathered from what has been said regarding the tensor tympani and stapedius muscles in the chapter on hearing. Distinct from this is our appreciation of pain or pleasure, and so also our estimation of temperatures. Adelon has indeed maintained that the cognizance of temperatures is the primary or chief function of this sense. It will be sufficient, however, for our purpose, leaving out these minor subdivisions, to direct our attention to the more important, and to consider the tactile organ as devoted to two uses: 1st, the appreciation of pressures; 2d, of temperatures. Pressures doubtless act upon the skin in a purely mechanical way; temperatures operate by inducing a variation in the rate of waste and nutrition. At a certain point, even this distinction ceases, for pressures, when they reach a sufficient intensity, interfere with the supply of arterial blood or the removal of venous, and thereby change the rate of nutrition and waste, acting, as far as this goes, in a manner not unlike that of the variations of temperature.

In man, the skin possesses tactility to a different degree in different regions. On the tips of the fingers and on the lips the sensory perception is most acute, while it is at a minimum on the trunk and thigh. In other mammals, which are covered with hair or wool, the sense of touch is much more restricted. Its proper organ is to be regarded as arising from a concentration of general sensibility of the skin upon a special construction, the papillary body, as it is termed. The organs of vision and hearing consist essentially of

Regional difference in tactility.

two portions, a receiving and a nervous, the former being constructed on the principles of optics in the one case, and of acoustics in the other. A similar doubleness of structure may be recognized in the instance now before us, though with a difference of effect, for in those cases the outer or receiving organ is for the purpose of more powerfully concentrating the influence received, but in touch it is the reverse. The office of the cuticle, which covers over the true skin, is to render it less sensitive to external impressions, and for this reason, therefore, it varies in thickness in different regions, being less developed on those portions that are more particularly devoted to tactile sensibility. Considering the hand, or, perhaps, more correctly, the tips of the fingers, as being chiefly devoted to the purposes of touch, no construction could be conceived of better adapted to that end. Placed at the extremity of the arm, a lever which is jointed at its middle, the elbow, and the fore part of which has a motion of partial rotation, pronation, and supination upon its own axis, the hand being carried so that its palm presents upward or downward, or in any of the intermediate positions included in the half-circular motion—jointed again by the bones of the wrist, so as to obtain a hinge-like movement, the hand may be flexed or extended almost 180 degrees upon the forearm. Its bony structure, subdivided into suitable pieces, is clothed with a multitude of muscles or their tendons. In the fingers and thumb the structure breaks up into five separate pieces, possessed of an incredible firmness when we consider the numberless motions which can be accomplished. The position and articulation of the thumb, which enables it to set itself in opposition to the other four digits, a feature which constitutes a hand, properly speaking, gives the power of grasping things perfectly, and makes the whole organ a perfect mechanism of prehension. The papillary structure, developed in its utmost refinement on the tips of the fingers, and fortified behind by the nails, which present moderate resistance to pressures, completes this contrivance, which, from its perfect adaptation to the uses to which it is devoted, its power, its delicacy, and the infinite movements which it can accomplish, is not surpassed as an example of the adaptation of means for the accomplishment of an end by any other structure of the body. There have been authors who have asserted that the superiority of man over other animals may be entirely accounted for by his possession of a hand—a statement which, though it can not be maintained in its generality, is yet a very good proof of the appreciation in which this wonderful instrument is held by those who have studied its construction and functions most closely.

Structure of organ of touch.

Between the indications that have to be dealt with by the hand as an organ of touch, and those dealt with by the eye and ear, there is an *essential* difference. The eye, for example, receives the pictures of ex-

ternal objects upon a surface, but the hand examines the solidity of bodies. The former is occupied with length and breadth; the latter with all three dimensions, length, breadth, and thickness conjointly. Our notions of solidity are to no little extent obtained in this way, as was proved in the case of Cheselden's patient, who had been blind from birth, and to whom vision was given by a successful operation for cataract, and still more recently by a similar case of Franz. In this instance, "a solid cube and a sphere, each of four inches diameter, were placed before the patient, at the distance of three feet, and on a level with the eye. After attentively examining these bodies, he said he saw a quadrangular and a circular figure, and, after some consideration, he pronounced the one a square and the other a disk. His eye being then closed, the cube was taken away, and a disk of equal size substituted, and placed next to the sphere. On again opening his eye, he observed no difference in these objects, but regarded them both as disks. The solid cube was now placed in a somewhat oblique position before the eye, and, close beside it, a figure cut out of pasteboard, representing a plain outline prospect of the cube when in this position: both objects he took to be somewhat like a flat quadrate. A pyramid placed before him, with one of its sides turned toward his eye, he saw as a plain triangle. This object was now turned a little, so as to present two of its sides to view, but rather more of one side than of the other: after considering and examining it for a long time, he said that this was a very extraordinary figure; it was neither a triangle, nor a quadrangle, nor a circle—he had no idea of it, and could not describe it: 'in fact,' said he, 'I must give it up.' An example of the close association which exists between the sense of touch and that of sight, in enabling the mind to form a correct idea of an object, is afforded in the statement of this patient, that, although by the sense of sight he could detect a difference in the cube and sphere, and perceive that they were not drawings, yet he could not form from them the idea of a square and a disk until he perceived a sensation of what he saw in the points of his fingers as if he really touched the objects. When he took the sphere, cube, and pyramid into his hand, he was astonished that he had not recognized them as such by sight, being well acquainted with them by touch."

Examination of solidity by the hand.

The mechanism for touch, as distinguished from the general dermoid sensibility, is the papillæ, which may be described as conical eminences on the cutis, at once solid and flexible, sometimes clavate in form, and sometimes having numerous points. They are about the $\frac{1}{100}$ of an inch in height, and the $\frac{1}{250}$ of an inch in diameter at their base, these dimensions varying, however, very greatly with the situation. They contain a loop of blood-vessels and a twig of a sensory nerve, for all the centripetal nerves, with the exception of those

Structure of papillæ of touch.

devoted to the special senses, may be regarded as concerned in this function. The papillæ contain an elastic substance—axile body, as it is termed—which serves to heighten the sense, and the yielding structure of the skin aids in the same effect. The papillæ are covered over with the cuticle, through which, therefore, all action on them must take place.

Fig. 203.

Simple papillæ, magnified 35 diameters.

Fig. 204.

Compound papillæ, magnified 60 diameters.

Fig. 203 (Todd and Bowman) represents simple papillæ of the palm, the cuticle having been detached. *Fig.* 204 (Kolliker), compound papillæ, with two, three, or four points: *a*, base of a papilla; *b*, *b*, *b*, separate processes; *c*, *c*, *c*, processes of papillæ whose bases are not visible.

The Pacinian bodies.

The mode in which the nerve fibre terminates in the papilla is as yet doubtful, some asserting that it is arranged as a returning loop, and some that it is by a pointed extremity. This latter mode is thought to be illustrated by the structure of the bodies termed Pacinian, which are ovoid in form, $\frac{1}{10}$ to $\frac{1}{15}$ of an inch in length, $\frac{1}{20}$ to $\frac{1}{30}$ in breadth, and attached by a pedicle to many of the cerebro-spinal and sympathetic nerve branches. Each consists of many concentric membranous layers, arranged like the coats of an onion, the interior ones closer than the exterior. They have a central cavity, distended by a fluid, which also intervenes between the coats. Across this cavity, and occupying exactly its axis, a nerve fibre, which has cast off its white sheath, passes, terminating at the other end either in branches or a knob. The use of these bodies is wholly unknown, and even their structure is doubtful, the existence of the central liquid referred to being denied by some anatomists.

The sensitiveness of different regions.

The sensitiveness of a part is in proportion to the number of papillæ it contains. Tables have been constructed setting forth the relations of different regions, as determined by placing a pair of compasses, the points of which were covered with cork, on the parts to be tried, the eyes being shut, and closing the compasses until the pieces of cork could no longer be distinguished as separate. It appears that this will take place on the tip of the tongue when the points are the $\frac{1}{24}$ of an inch apart; on the tip of the third phalanx, at the $\frac{1}{12}$ of an inch; on the lips, the one sixth of an inch; tip of the great toe, half an inch; the lower part of the occiput, 1 inch; and on the middle of the thigh, $2\frac{1}{2}$ inches.

No part of the skin is entirely devoid of sensitiveness, as Kolliker has

shown by examinations with a fine needle. At first he thought he had found some places which were quite insensible, while in others the slightest touch produced sensation; but on carrying the investigation farther, it appeared that the very same place was sometimes sensible and sometimes not, so that finally he came to the conclusion that the very smallest portions of the skin are sensitive. But since, even in the palm of the hand, the papillæ containing nerves are widely dispersed, and in other places occur but rarely, or even not at all, he infers that it is necessary to assume the existence of non-medullated fibres in all the papillæ, or to have recourse to the nervous plexus at their base, since he believes it is not possible to demonstrate nerves in every one of those bodies.

Every part of the skin is sensitive.

The nerves supplying the papillæ may perhaps be said to ascend through the cutis, continually branching, and forming eventually terminal plexuses. The primitive tubules themselves dividing at an acute angle into two, and entering the papillæ, they are united at their extremities in a loop. Of course, this construction involves the fact that they have freed themselves from the white substance of Schwann. The impression made on these exposed nervous fibrils is by many regarded as of a purely mechanical kind. They may be affected not merely by vertical pressures, but likewise by those exerted in the direction of the plane of the skin, and this accounts for tactile sensation on portions of that surface which are either sparsely or not at all supplied with nerve fibrils. To this effect the unyielding and horny texture of the cuticle doubtless contributes.

Papillary nerves.

No papillæ are found in invertebrate animals. Among vertebrates they are variously disposed. In lizards they occur under the toes; in the chameleon, and some of the ant-eaters, which use their tails for tactile purposes, they are found upon that organ. In the spring season of the year they are temporarily developed on the thumb of the frog. Among birds they are found upon the toes, or, if web-footed, upon the web; in the mole on the tip of the snout. In the tapir and elephant they occur upon the trunk; among the quadrumana, on the hands and feet, and in some also upon the tail. The whiskers of the cat, the rat, the rabbit, may be regarded as appendages to the tactile organs, enabling them to find their way through narrow passages in the dark. Among articulata the antennæ have doubtless, with their other functions, a similar use. Men who have become blind often guide their steps by means of a stick, judging from the sensations which its contact with surrounding bodies imparts to the hand: it is in all respects a temporary antenna.

Touch in other vertebrates.

Our estimates of the hardness and softness, roughness and smoothness of bodies, is primarily dependent on indications derived from the sense

Estimate of physical qualities by touch.

Distinction between feeling and touching.

of touch. We should make a distinction, however, with Magendie, between feeling and touching, the former being essentially passive, the latter active; and though we usually suppose that, of all our senses, touch is the most reliable, it often conveys to the mind illusory impressions, as, for instance, in the well-known experiment of Aristotle, when the tips of the fingers are crossed over each other, and a pea rolled beneath them, it seems as if there were two peas, one under each finger. The indications of touch are generally more correct than those of feeling. Thus, if we close our eyes, and another person moves the tip of our finger over an unknown surface, he can completely deceive us by duly varying the pressure, and make us believe that it is concave or convex, whereas it may be flat; but if we pass our fingers over the surface ourselves, we very quickly come to a true conclusion, because now we are conscious of the exertion of muscular power; and from what has been said respecting hearing, we may infer how delicate our estimate of muscular exertion is. The former is therefore an example of feeling, the latter of touch.

Tickling.

Connected with this distinction are the singular phenomena of tickling; the regions most readily affected by this are those of low tactile sensibility. A person can not tickle himself, though it is said that cases are upon record in which one has been tickled to death by another. As in the other cases, the mind can direct attention exclusively, for the time being, to some one indication of touch, which, though it may be apparently insignificant in itself, becomes, after a while, perfectly intolerable, as the pressure of a hair, a gentle draught, or the falling of water, drop by drop, on the top of the head; and, as with them, an impression which is made does not instantaneously disappear, but will sometimes continue for quite a considerable time. A ring or other article that has been long worn will leave a sensation, though it may have been removed.

Remains of impressions.

Besides affording an estimate of external pressures, the sensory organ enables us to discover variations of temperature. It may therefore be thus effected by bodies upon contact or by bodies at a distance; and though we usually confound the two indications together, there is, in reality, a distinction between them; thus, in certain conditions of paralysis, the indications of the contact of bodies may remain, but those of heat and cold may have totally disappeared. On examining a surface from which the skin has been removed, it does not appear capable of distinguishing hot from cold bodies, but only communicates to the mind an indefinite sensation of pain; nor can we create sensations of heat or cold by any irritation of the nerves. The measure of temperature by the agency of the skin is very far from being exact, as has been

Perception of temperature distinct from that of pressure.

Ideas of heat and cold can not arise artificially.

proved by the simple experiment of dipping the finger into very warm water, and then the whole hand into water many degrees cooler. The increased extent of surface seems to overcompensate for the lower temperature, and we come to the erroneous conclusion that the cooler specimen is the warmer of the two samples.

Deceptions of the sense of touch.

As sounds may be heard which have no reality, but merely originate in the brain, or spectral illusions may be seen, so the sense of touch is subject to similar hallucinations, as a sensation of pressure or weight, or the crawling of insects on the skin; and though we can not, by artificial irritation of the nerves, give rise to impressions of heat and cold, those effects very frequently occur in this interior or subjective way.

Subjective sensations of touch and temperature.

CHAPTER XXIII.

OF SMELLING, AND THE MEANS OF DISTINGUISHING GASEOUS AND VAPOROUS SUBSTANCES.

Structure of the Organ of Smell.—Its proper Instrument the First Pair of Nerves.—Limited Region of Smell.—Conditions of its perfect Action.—Duration of Odors.—Their Localization.—Subjective Odors.

By the sense of smell we are able to distinguish many gaseous and vaporous substances from one another. They enter the nostrils with the respiratory current, and are brought in contact with the olfactory or Schneiderian membrane. Though received at first in the elastic state, they become dissolved in the mucus which moistens that membrane. It does not follow, however, that all vaporous substances give rise to the perception of an odor; for example, water itself communicates no sensation whatever. Again, there are other bodies, as, for instance, musk, which yield an odor far more powerful than corresponds to their loss of weight. Thus it is said that that substance may be exposed for years in an apartment, diffusing all the time its penetrating emanations, and yet not becoming lighter. Such statements are, however, on their face, exaggerations. There can be no doubt that the olfactory organs detect extremely minute portions of matter. In most cases, elevation of the temperature of a body increases its odorous effect.

Sense of smell for gases and vapors.

Delicacy of this perception.

The primary uses of the function of smell are for a discrimination of the qualities of food, or its condition, and also for enabling an animal with greater facility to provide itself with supplies. Hence the development of this structure takes place in the utmost perfection among the carnivora, which often depend almost exclusively upon

Uses of smell.

this faculty for the pursuit of their prey. But even in the herbivora it is well marked, and furnishes them, though less exactly, similar indications. In man, though this sense is less acutely developed, it applies itself to a greater variety of objects, and doubtless enables him to appreciate differences among odors in a more correct manner than in the case of the lower animals.

Mechanism of the olfactory organ.

The general principle involved in the construction of the organ of smell is to expose an extensive and constantly moistened surface to the air brought in by the respiratory current. Of course, other things being equal, the larger the surface, the more perfect the sense. The object of gaining a great extent of superficial exposure under a relatively small volume is accomplished by spreading the sensitive mucous membrane on projections or shelves, which also serve the purpose of intercepting the incoming current of air. It is in reptiles and birds that turbinated processes first make their appearance. In air-breathing animals, the organ of smell is essentially an appendix to the respiratory mechanism, its action depending entirely upon the play thereof. But, though the material submitted to the olfactory membrane in this manner is presented in the vaporous or gaseous state, it is intermediately dissolved, as has been stated, in the liquid mucus which covers that membrane, before it can affect the ramifications of the olfactory nerve.

The nose, thus constituting the commencement of the respiratory tract, forms a characteristic feature of the countenance. It is composed in part of bones and in part of cartilages, covered over with muscles and integument. Its five cartilages give to it shape in its inferior portion, and, by their elasticity, enable it to resist external injury. The whole surface of the nasal cavities is covered over with mucous membrane, to which the names of pituitary or Schneiderian membrane have been given. This mucous membrane likewise extends into the maxillary antrum, ethmoid, and sphenoid cells, or sinuses which are adjacent, and open into the same nasal cavity. The Schneiderian membrane is highly vascular, and receives its nervous supply from the nasal branches of the fifth pair, which give it common sensibility, but its olfactory function depends on the distribution which a certain portion of it receives from the first, or olfactory nerve.

Fig. 205.

Fig. 206.

Fig. 205 illustrates the distribution of the olfactory nerve on the septum of the nose. *Fig.* 206 is its distribution on the outer wall of the nasal fossa.

That the function of the first pair of nerves is olfactory is proved by

many facts. Animals in which these nerves have been divided are no longer affected by odors of any kind, and, generally speaking, the greater the development of these nerves, the acuter is the sense of smell. In persons in whom this sense has been defective or totally absent, or in those who have been troubled with unpleasant odors of a subjective kind, post-mortem examinations have shown a corresponding absence or lesion of these nerves.

Function of the first pair of nerves.

In man, the proper olfactory organ is formed by the distribution of the olfactory, or first pair of nerves, on the mucous membrane which covers the upper part of the nose, the internal set of filaments being disposed on that of the septum, the external on that of the superior and middle spongy bones. The membrane is very vascular, and covered with a thick, pulpy epithelium. The filaments distributed to it have lost the white substance of Schwann. It is those parts alone to which these filaments are distributed which possess the sense of smell, the adjacent cavities, as, for example, the frontal sinuses, not participating in the function, as has been proved by the injecting of the vapor of camphor or other odoriferous bodies into them. It seems to be necessary for the vaporous or gaseous substances to be dissolved in the moisture which covers the olfactory membrane in order to their exerting a proper effect. If, by chance, the membrane is too dry, the sense of smell is temporarily lost, and the same likewise occurs if it be unusually moist.

From the mode of distribution of the olfactory nerve, it follows that the sense of smelling is restricted to the upper portion of the nasal cavity; and, for this reason, when we desire to detect odors with unusual precision, the air is drawn violently into that region by sniffing. On the contrary, we avoid the perception of odors by breathing through the mouth, or, as the common phrase is, by holding the nose. Since the perfection of the sense requires that the olfactory surface shall neither be too dry nor too cold, an advantage is gained by placing it high in the cavity, where it is free from the disturbing effects of the dry air introduced by inspiration, which becomes moistened and warm before it reaches the place of action.

Limited region for the sense of smell.

Conditions for its perfect action.

Just as we make a distinction between a musical sound and a noise, so should we distinguish between an odor and such impressions as arise from tickling, pressures, the use of snuff, mustard, pepper, and pungent bodies, for these act as mere irritants, and many of them can produce analogous effects on other portions of the surface of the skin. Odors do not give rise to the impressions of pain, and, indeed, the nervous mechanism having charge of the action is totally different in the two cases. Odors operate, as we have said, upon the olfactory nerve, but these other impressions are made upon the nasal

Distinction between odors and irritation.

supplies from the fifth pair. The upper part of the nasal cavity is therefore devoted to the proper sense of smell, the lower portion to general sensation.

Duration of odors.

In one respect there is a striking difference between this sense and vision and hearing. We can perceive many luminous impressions at the same time, or hear many sounds in rapid succession; but not so with odors. We can smell only one thing at a time, or, at all events, the impression remains long upon the olfactory apparatus, perhaps because the odoriferous substance remains dissolved in the attached moisture. The identification of substances by their odor necessarily implies a resort to recollection or memory, and sometimes we have to apply the fragrant object again and again to the nose, before we can recall with satisfactory precision its name.

Comparative anatomy of smell.

In the lower animals the sense of smell is probably localized in some parts of the skin; many of them display instincts which seem to imply the possession of such a sense. Insects also, by smell, are often led to their food or to one another.

The variable current of air introduced by respiration compensates in some degree for the want of mobility of the nose, which may be regarded, in air-breathing vertebrated animals, as consisting of a diverticulum from the respiratory passages. In fishes, however, the olfactory cavity is not connected with the respiratory passages: there are no posterior nares. The circumstance of their living under water disables them from appreciating the odorous peculiarities of gases and vapors. In the whale the organ is altogether absent, being replaced by the mechanism for receiving air and blowing out water. In other tribes the acuteness of the sense is in proportion to the development of the olfactory ganglia: in reptiles it is feeble; in birds, more developed; in carnivorous animals, still more. But here again it exhibits a special restriction, since there is reason for supposing that carnivorous animals are insensible to the perfume of flowers, while herbivorous ones distinguish them perfectly. In man, as we have said, the sense is less developed, but it has a wider range.

Localization of odors.

The localization of odors is effected in a much less perfect manner than the localization of sounds. The principle by which it is accomplished is obviously that of determining the direction of maximum intensity, and this involves necessarily the constant exercise of memory and comparison. The surprising manner in which this can be accomplished by animals whose sense of smell is acute, as, for example, by the dog, is extremely interesting. From the different manner in which various odors affect different individuals, there is no general standard of comparison to which they may be referred, as there is in the case of colors and of sound. Scents which may be highly disagreeable to one are acceptable to another person. By constant exposure, the faculty may

become so benumbed as to be unable to distinguish some altogether. Thus Turner found "that the flower of the iris persica was pronounced of pleasant odor by forty-one out of fifty-four persons, by four to have little scent, and by one to be ill-scented. Of thirty persons, twenty-three held the anemone nemorosa agreeable in its perfume, and seven did not think that it smelled at all." Various effects of odorous impressions.

Diseases of the central organs will sometimes give rise to the perception of subjective odors, just as they do to spectral illusions or sounds in the ears. Subjective odors.

CHAPTER XXIV.

OF TASTE.

Conditions for Taste.—Structure and Functions of the Tongue.—Tactile and Gustative Regions of the Tongue.—Complementary Tastes.—Subjective Tastes.

THOUGH the function is participated in by other portions of the oral cavity, the tongue is to be regarded as the organ of taste. The physical conditions under which savors are perceived is that the substance shall be presented in solution in water, or, at all events, in the saliva. From vision, hearing, and smell, the sense of taste differs in the circumstance that it requires the contact of the acting body; and, to a certain extent, the same distinction which has been made regarding such substances as can act on the olfactory mechanism might also be made here; that is to say, that there are two classes of agents which affect the organ—those which produce a mere pungent sensation, and those which excite savors, properly speaking, for the former will frequently give rise to specific action when applied to other portions of the surface of the skin. Conditions for taste. Irritations and savors.

Sensations of taste are very frequently conjoined with olfactory perceptions, so that we mistake the one for the other. There are many substances, reputed to have a powerful flavor, which become tasteless when the nose is held; and this remark applies more particularly to such as are at the same time volatile and soluble in water. However, irrespectively of this, some of those bodies which produce the most intense and permanent impression on the organs of taste do so merely in virtue of their solubility, as, for example, quinine, which is a non-volatile body. The intensity of such action depends on the duration of contact and the degree of exposure of the substance to the tongue, so that the papillæ may, as it were, become thoroughly permeated. Connection of olfactory perceptions and tastes.

The idea of taste may arise irrespectively of the presence of any actual substance. A sharp blow will produce it, as also the passage of a feeble voltaic current. It was, indeed, in this way that the first observation in galvanic electricity was made. A narrow jet of air directed upon the tongue causes a taste resembling that of saltpetre. If the tongue be dry and parched, its power of discriminating tastes is greatly enfeebled, and the same thing takes place if its temperature is very much changed, either by elevation or depression, as by keeping it for a short time in contact with hot or very cold water.

Tastes dependent on accidental agents.

The action of the tongue, as the organ of taste, depends upon the papillæ which are on its surface. These structures give to the upper portion of the tongue its rough appearance. They are of three kinds: 1st. The conical papillæ, which are the most numerous; 2d. The circumvallate papillæ, which are situate near the base of the organ, and which are from $\frac{1}{20}$ to $\frac{1}{12}$ of an inch in diameter, with a crater-like depression, round the edge of which is a groove, and again a circular elevation; 3d. The fungiform papillæ, which are chiefly on the sides and tip, their shape being conical, the narrow end of the cone being downward. The epithelium of the tongue is less dense over the fungiform papillæ, and hence their projecting appearance: it is more dense over the conical papillæ, and projects from them in processes which present an aspect like that of hairs. Some of them contain hair-tubes. Besides these, the surface of the tongue presents a papillary structure resembling that of the skin—secondary papillæ, as they are termed. It is supposed that the conical papillæ are chiefly organs of prehension; the others are organs of taste, but that function is participated in by other portions of the surface of the mouth, as, for example, the soft palate, its arches, and the tonsils.

Structure of the papillæ of taste.

Fig. 207 represents the surface of the tongue and the adjacent parts: *a*, *a*, lingual papillæ; *b*, *b*, circumvallate papillæ, disposed along two converging lines forming the lingual V; *c*, foramen cœcum; *d*, *d*, fungiform papillæ; *e*, *e*, filiform papillæ; *f*, frænum epiglottidis; *g*, epiglottis; *h*, anterior pillar of velum; *i*, stylo-glossus; *l*, isthmus of the fauces; *m*, uvula; *n*, velum pendulum palati; *o*, hard palate; *p*, raphe; *q*, *q*, orifices of the excretory ducts of the palatine glands; *r*, palatine glands, the mucous membrane being removed; *s*, palatine glandules; *t*, mucous membrane covering the same glands; *u*, palatine tubercle; *v*, *v*, section of the lower jaw.

Fig. 207.

The tongue.

The organ of taste is placed at the commencement of the digestive canal; hence the characters of substances may be examined with deliberation while they are yet under the control of the will, for when once a body has entered the œsophagus it is swallowed involuntarily. The tongue, therefore, gives warning of the presence of deleterious substances, and in no small degree excites the appetite by receiving the impression of pleasant flavors. The essential condition under which it acts is a moist state of its surface, for the dry tongue, though it enjoys common sensibility, after the manner of any portion of the external tegument, does not enjoy taste. One of the duties of the salivary glands is incidentally to maintain this moistened condition. To a certain degree, taste may be regarded as a refinement on touch. It differs from vision and hearing in the peculiarity that there is no single nerve of special sense individually devoted to it, for the front of the tongue is supplied by the lingual branch of the fifth pair, and the back by the glosso-pharyngeal. Its entire nervous supply is derived from four different sources: the lingual, the hypoglossal, the glosso-pharyngeal, and the sympathetic, representing therefore special sensibility, muscular motion, common sensibility, and sympathetic relation. That the hypoglossal is the nerve of motion, or muscular nerve, is proved beyond doubt by its section, after which the motions of the tongue are destroyed, but taste and touch remain. The individual duty discharged by the glosso-pharyngeal, and the lingual branch of the fifth pair respectively, is not so clearly determined. Section of the former is attended with loss of taste, though it is not yet proved that there is a loss of all kinds of taste. If the lingual branch of the fifth be divided, common sensation at the tip of the tongue is destroyed, and there is evidence that with this the appreciation of certain tastes disappears. The glosso-pharyngeal is distributed to the circumvallate papillæ, and it is said that in some birds the lingual is suppressed. Upon the whole, therefore, it may be concluded that these nerves are conjointly engaged in the sense of taste, the glosso-pharyngeal being engaged with those flavors which affect the back part of the tongue, the lingual with those which affect the tip.

Uses of the sense of taste.

Nerves of the tongue.

Illustrations of the distribution of the hypoglossal nerve have already been given in its description, under the title of the twelfth pair.

The surface of the tongue presents the tactile and gustative powers in an inverse manner. Examined by the method described in the chapter on touch, the compasses must be opened to a great extent, as we pass from the tip toward the back of the tongue, in order that a double impression may be perceived. This condition appears to be in accordance with the requirements of the organ, common tactile sensibility being most necessary at its outer extremity, and this

Tactile and gustative regions of the tongue.

gradually passing off into the refinement of taste. The action of any given substance may be increased by motion and pressure, as when it is rolled over the tongue, or held thereby. Its sense of discrimination may be rendered more acute by education.

Duration of tastes.

As with the organs of the other senses, so with this, an impression made upon it does not instantaneously cease, but remains for a certain period of time, indeed, in this instance longer than in those. Hence many substances acting in rapid succession give rise to a confused effect, though it is said that, out of such interminglings, an accomplished epicure can fasten his attention on one, and continue to recognize it just as we recognize and follow the sound of one instrument in an orchestra. No explanation has as yet been given of the manner of action of different tastes, though it is asserted that some act upon one, and some upon another set of the papillæ. After-tastes are also observed, which are occasionally of a complementary kind, as, for instance, the intensely bitter taste of tannin is followed by a sweetness. These after effects modify the taste of substances which may be taken while they last. They therefore form an ample subject for the profound contemplation of the epicure, and should occupy the serious attention of the cook. They may be illustrated in a general manner by the injurious effect of sweet substances upon the flavor of delicate wines.

Complementary tastes.

Electrical and subjective tastes.

It has been mentioned that the passage of a voltaic current through the tongue causes an alkaline or acid taste. Some experimenters deny the correctness of this statement, and assert that the impression is merely metallic. The effect, however, depends upon the intensity of the current employed, or on the nature of the pieces of metal used. If the current has power enough to decompose the salts of the saliva, acid or alkaline tastes will be detected, according as the direction of the current is made to vary, and the acid or alkaline body is disengaged on the upper or under side of the tongue. Subjective tastes arise in diseases of the nervous centres, but these are often rendered obscure by the exudations and furred condition of the tongue. Dogs, into the blood-vessels of which milk has been injected, have been observed to lick their lips; and from this it has been inferred that the presence of substances artificially introduced into the circulatory current may be detected by the organ of taste.

CHAPTER XXV.

OF ANIMAL MOTION.

Ciliary and Muscular Motion.—Description of Cilia and the Manner of Action.
Muscular Fibre: its Forms, Non-striated and Striated.—Muscle Juice.—Manner of Contraction of a Muscle: its supply of Blood-vessels and Nerves.—Its Chemical Change during Activity.—Its Rise of Temperature.—Effect of Electrical Currents.—Duration of Contractility.
Doctrine that Muscle Contraction is the result of Muscle Disintegration.—Manner in which ordinary Cohesion is brought into play.—Manner of Restoration.—Removal of the Heat and Oxidized Bodies.
Rigor Mortis.—Connection of Muscle for Locomotion.—Of Standing.—Walking.—Running.

Animal motion.

It was formerly held that animals are distinguished from plants by the possession of the power of locomotion, a doctrine which can now no longer be regarded as true. It was also believed that the muscular movements of animals are due to the influence of the nerves, and that a muscular fibre contracts only when stimulated to do so by a nerve. This makes the possession of a nervous system essential to the motions of animals. These doctrines also are erroneous.

Animal motion is of two different kinds: 1st. It is accomplished by vibrating cilia; 2d. By the contraction of cells arranged in the form of a fibre.

OF CILIARY MOTION.

Description of cilia and their movements.

The epithelial cells of the cylindrical and of the tesselated kind are occasionally arranged with delicate projecting striæ on their free extremities. The length of these varies from the $\frac{1}{600}$ to the $\frac{1}{10000}$ of an inch. These striæ are termed cilia, and the cells are said to be ciliated. Examples are presented by the mucous membrane of the respiratory surface and of the nasal cavities; an illustration is given in *Fig.* 208. The cilia may be regarded as prolongations of the cell wall itself. They exhibit a vibrating motion back and forth, which recalls the movements of stalks of grain in a field as the wind is passing over it, the ears bending down and rising again in the breeze, and throwing the whole surface into waves. The cilia also exhibit a movement like that known as the feathering of an oar, or sometimes as turning round upon the point of attachment, as upon a centre, giving rise to a sort of conical motion, the free end describing a circle. These motions seem to

Fig. 208.

Ciliated cells.

be perfectly involuntary, for they not only take place long after death, but even in detached portions, the ciliary cell being uninjured and entire. The seats of ciliary action are always moistened surfaces. The condition for the continuance of the motion after death is accordingly that the surface shall be kept moist, but it is also necessary that a certain temperature should be observed, which in warm-blooded animals must not fall below 42° F. Even after the motion has completely ceased, a solution of carbonate of potash re-excites it, but this does not take place with ammonia, because it injures the ciliated cells.

Ciliary motion is independent of nervous agency. The control of temperature and of chemical reagents over it shows that it is of a physical nature.

Uses of ciliary motion.

In the lower orders of life ciliary movement is relied on both for the purposes of locomotion and prehension. *Fig.* 209 illustrates this in the case of a vorticella, the upper edge of which shows such a mechanism. It is often stated that in the higher animals the object is to determine a movement of the liquid which moistens the ciliated cells in the direction of the outlet of the tube, or other surface which they line. In this way the action of the cilia may tend to the expulsion of material from the air-cells of the lungs into the bronchial tubes. In reptiles, whose urinary tubelets are furnished with this mechanism, the secretion may be urged thereby in the proper direction.

Fig. 209.

Ciliated animalcule.

Embryonic contractile tissue.

The contractile tissue which enables such animals as the hydra (*Fig.* 210) to execute movements of prehension and locomotion may perhaps be regarded as the rudimentary state of the structures next to be described. The annexed sketch, from Trembley, illustrates the manner of progression of this animal. No trace of a proper muscular fibre, and none of a nervous system, have hitherto been detected in it.

Fig. 210.

Hydra walking.

Of Muscular Motion.

The muscular system consists of muscular fibres, tendons, bones, together with various accessory parts, such as ligaments, sheaths, bursæ mucosæ, synovial capsules, fascia. Its action depends on the primary fact that, under appropriate influences, muscular fibre shortens.

Each voluntary muscle consists of a collection of fasciculi, which ex-

Fig. 211.

Striated muscular fasciculi, magnified 125 diameters.

hibit the characteristic appearance of transverse striation, as in the

Fig. 212.

Human sarcolemma.

Fig. 213.

Sarcolemma of fish.

photograph of muscular structure of the frog (*Fig.* 211). The primary fasciculi are collected into larger bundles, secondary muscular fasciculi, held together by connective tissue, and these, again, into still larger, the tertiary. Voluntary muscular fasciculi.

The primitive fasciculus is enveloped in a delicate sheath, the sarcolemma, as shown in *Fig.* 212, in which the fasciculus, though torn across, is held together by the sarcolemma. The specimen is from the human muscle. *Fig.* 213 is a good representation of the same fact. It is given by Todd and Bowman from the skate. The sarcolemma is a delicate membrane, which, though of great tenuity in man, may be made visible by the action of acetic acid or alkalies. Within the sarcolemma the primitive fasciculus is seen to be composed of many parallel fibrils, which may, by maceration or chemical agents, be separated from one another. These fibrils present a beaded aspect, and, since their constituent elements are arranged side by side in parallel planes, they give to the fasciculus the appearance of striation it presents. Ultimate muscular fibril.

Fig. 214.

Ultimate muscular fibre, magnified 200 diameters.

The longitudinal striation of the fasciculus arises from the fibrils themselves. Here and there, in the interior of the sarcolemma, nuclei occur irregularly, and with them fat granules. The fibrils, with the fat and a liquid, fill the sarcolemma, without leaving any central canal or hollow axis.

Fig. 214 is a photograph of ultimate muscular fibre of the pig, from one of Mr. Lealand's preparations. The rectangular form of the constituent cells is well seen at *a*, *a*, *a*. At *b*,

probably by reason of a twist, tension, or undue strain, a spiral appearance is presented; *c*, *c* are the primitive fasciculi.

Muscle juice.

A fluid surrounds the fibres of striped muscles, and the fibre cells of smooth ones, which is wholly different from the plasma of the blood. The experiments of Schultz show that this fluid contains a large amount of casein, a conclusion of considerable importance, since, if there were any doubt of the occurrence of that substance in the blood, this fact, at all events, renders it certain that the mammary gland is not necessary to its formation. That the substance thus occurring is casein is proved by the action of rennet.

Muscle juice undoubtedly arises within the sarcolemma through which it exudes. Each fibre therefore presents four objects: the syntonin, the nucleus, the sarcolemma, and the muscle juice. That the muscle juice arises in part from the functional activity of the fibre, and is immediately derived from the waste of its syntonin, and that, in its turn, the syntonin is closely allied to the substance of the nucleus, is shown by their exhibiting almost the same chemical reactions with alkalies, acids, etc.

The sarcolemma is not, however, filled with syntonin; it contains besides, as stated above, a certain quantity of fat, as may be demonstrated by removing from the sarcolemma its syntonin by acids, when a granular material will be left. That this is fat is proved by its solubility in sulphuric ether.

Sarcolemma.

The sarcolemma does not belong to the protein class of bodies, but is rather analogous to elastic tissue. The color of muscle appears to be not so much due to the blood as to a special pigment, which, perhaps, adheres in a free state to the fibrils. The muscle juice contains relatively far more potash salts and phosphates than the blood, as is shown by the following table from Liebig.

For one hundred parts of soda there occur,

In the	hen,	40.8	of potash	in the	blood,	and	381	in the	muscle juice.
"	ox,	5.9	"	"	"		279	"	"
"	horse,	9.5	"	"	"		285	"	"
"	fox,	—	"	"	"		214	"	"
"	pike,	—	"	"	"		497	"	"

Two forms of muscular fibre, non-striated and striated.

It is commonly stated that muscular motion is accomplished by fibres of two different kinds: 1st. The simple, non-striated, unstriped, or organic fibre; 2d. The striated, striped, or voluntary fibre just described. Though this subdivision may be convenient, it can scarcely be regarded as accurate, since the former variety passes by insensible degrees during development into the latter, and cases, indeed, are not wanting in which the same fasciculus presents in different parts both conditions at once.

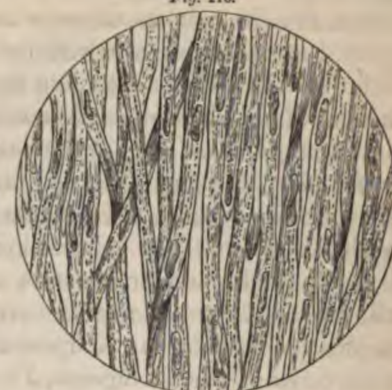
The non-striated muscular fibre, *Fig.* 215, consists of translucent bands

of a soft granular material, varying from the $\frac{1}{2000}$ to $\frac{1}{5000}$ of an inch in

Fig. 215.

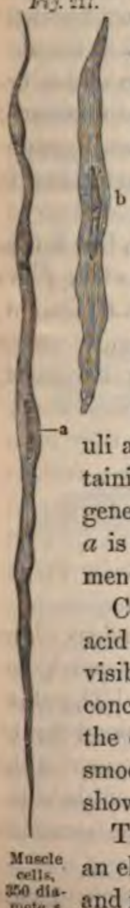
Unstriped fibres.

Fig. 216.



Unstriped fibres in acetic acid.

Fig. 217.



Muscle cells, 350 diameters.

breadth, and exhibiting here and there the traces of nuclei, particularly after the fibre has been acted on by acetic acid, as is shown in *Fig.* 216. Each fibre may be regarded as an arrangement of nucleated cells, the nucleus being of a cylindroid or spindle form. The contractile content within is syntonin. Non-striated fibre is not usually attached to fixed points, as to bone, but by being collected into parallel bundles, different bundles interlacing with one another, contractile planes or surfaces are formed, such as the cylindrical coat of muscular structure of the digestive tube, or the contractile layer of the urinary bladder. Similar fibres, imbedded in the skin and connective tissues, communicate to them the quality of corrugation or contractility. The fasciculi are bathed externally with an acid juice, characterized by containing salts of potash, phosphoric acid, creatine, and inosite. The general appearance of fibre cells of this class is given in *Fig.* 217: *a* is from the small intestine of man; *b*, from the fibrous investment of the spleen of the dog. (Kolliker.)

Non-striated fibre.

Contractile fibre cells present the following reactions: Acetic acid causes the fibre to swell, and makes the nucleus more visible; it occasions a complete dissolution when in a concentrated state. Dilute hydrochloric acts in a similar manner, the effect in this instance being the same with the fibres of both smooth and striped muscle. The examinations thus far made have shown no difference in ultimate composition between these forms.

Contractile fibre-cells.

The striated muscular fibre consists therefore of fasciculi, with an elastic investment of sarcolemma, collected into bundles, and invested with perimysium. The contractile constituent

Striated fibre.

is syntonin; and though the general rule is that the primitive bundles shall run isolatedly and parallel to each other, in certain cases they anastomose, *Fig.* 60. In its ultimate construction, the form of fibre may be regarded as consisting of a series of cells, as shown in *Fig.* 214, the diameter of which varies according to the actual condition of the muscle, whether it is in the contracted or relaxed state, but which may be taken, on an average, at the $\frac{1}{10000}$ of an inch. The cells are placed end to end, the boundary walls upon the end presenting the appearance of a delicate transverse line. Each cell consists of two portions, a central spot and a pellucid border. The pellucid border is considered by Dr. Carpenter, whose views of muscular structure we are here presenting, to be the cell wall, the central space being the cavity of the cell filled with some highly refracting substance. Dr. Carpenter speaks of the central spot as dark; an inspection of the photograph, *Fig.* 214, proves that it may be light if exactly in focus. When the fibril is in a relaxed state the longest axis of each cell coincides with the length of the fibril, but when contraction occurs this axis shortens, and a shortening of the entire fibril is the result. A number of these fibrils, placed side by side, constitute a fasciculus; indeed, there may be many hundreds of them thus bound together. When such a fasciculus is forcibly ruptured it presents different appearances, according as the ends or sides of its constituent cells have cohered most strongly together. If the lateral cohesion is weakest, the fasciculus tears into its constituent fibrils, as was shown in *Fig.* 214, but if the end cohesion is the weakest, it will tear into discs or plates, as in *Fig.* 218. The fasciculus is thus a bundle of fibrils, its diameter varying very greatly, and being, in man, from the $\frac{1}{200}$ to the $\frac{1}{500}$ of an inch; in females it is, on an average, smaller. Each fibril is a linear series of coalesced cells. The cells, as they form the fibril, lose their rounded and assume a rectangular appearance, as shown at *a*, *a*, *Fig.* 214. It therefore appears that each fibril must have its own investing sheath, the representative of the walls of the little cells which have coalesced, and this, though not usually admitted by anatomists, appears plainly in the photograph from which that figure is taken. In length, muscular fasciculi vary from the sixth of an inch to two feet. The larger animals furnish some that are even much longer. The normal form is doubtless cylindrical, but this is constantly departed from, each accommodating itself to the pressure of the adjacent ones. The sarcolemma serves as a partition between its included fibrils and the capillary blood-vessels and nerves, which imbed themselves in the rounded angular spaces between adjacent bundles. The cross section of a portion of muscle shows the manner in which the sarcolemma and the fibres

Fig. 218.

Muscular fasciculi torn in discs.

are arranged. *Fig.* 219 is from the human biceps, and *Fig.* 220 from

Fig. 219.

Transverse section of human muscle.

Fig. 220.

Transverse section of muscle of teal.

Muscular fasciculi.

the pectoral muscle of the teal. Since it is in the interspaces between the rounded fasciculi that the blood-vessels lie, the tissue is more vascular as its fasciculi are of less diameter.

It has already been stated, in connection with *Fig.* 211, that the striated form of muscular fibre derived its name from the circumstance that, when examined by a sufficiently high power, it appears to be crossed by delicate transverse lines, the longitudinal separations between the fibrils being also visible. This is seen in the specimen of insect muscle represented in the photograph, *Fig.* 221, and under a still higher magnifying

Fig. 221.

Non-fibrillated insect fasciculi, magnified 50 diameters.

Fig. 222.

Non-fibrillated insect fasciculi, magnified 200 diameters.

power in that of *Fig.* 222. The distance between the transverse striæ varies with the condition of the muscle, but on an average it is represented as being about the $\frac{1}{9000}$ of an inch. Many more striæ are crowded together when contraction takes place, and they retire from each other as soon as relaxation occurs.

Muscle juice.

It is said that the voluntary muscles contain in their muscle juice more acid than is enough to neutralize all the alkali of the blood. The electro-chemical relations of this interfascicular

acid juice and the alkaline plasma of the blood are doubtless the cause of the production of those electric currents which have been demonstrated in the muscles. It does not follow, therefore, that these currents occur in the natural state: they may be the result of the experimental arrangement for their own detection, since it has long been known that an acid and an alkaline juice, separated from each other by a conducting organic body, will form an effective voltaic circle.

Syntonin.

Of the contractile element of muscular fibre, syntonin, it may be remarked that it can be dissolved by the aid of dilute hydrochloric acid, and that it differs from fibrin of blood not only in that respect, but also both in its ultimate composition and physical and chemical qualities. In certain cases it seems to degenerate into fatty substance. In the growth of a muscle, the constituent fibrils increase in number and in length, their diameter remaining, however, nearly the same as in the early periods of life. The thickening of a muscle is, therefore, not so much due to the thickening of its constituent fibrils as to their increase of number.

Manner of contraction of a muscle.

The contraction of a muscular fibre does not take place throughout its whole length at once; it generally begins at the end, a change of aspect arising from the approach of the opaque centres of the cells to one another, and this occurring simultaneously across the whole fibre. This approach may, however, ensue in different parts of the length at the same time, the sarcolemma being raised up in bullæ as the contraction takes place. This effect is shown in *Fig.* 223,

Fig. 223.

Contracting muscle of Dytiscus.

in which the thickened portion of the contracted middle space of the muscle is surrounded with the sarcolemmic bullæ. The same is demonstrated in *Fig.* 224, which represents the border of a muscular fasciculus in a young crab, with a spot of contraction, and the sarcolemma elevated along the edge. In these cases the contraction is brought on by the action of water, which, in some measure, may exaggerate or disturb the phenomena. *Fig.* 225 exhibits, under the same circumstances, a fasciculus from the eel, *a* being the uncontracted, *b* the contracted part, on the edge of which the sarco-

Fig. 224.

Sarcolemma raised in bullæ.

Fig. 225.

Fasciculus contracting.

lemma is again raised up. The two latter illustrations are from Todd and Bowman.

Different portions of the length of the fibre assume this condition at different moments, and hence the whole structure is thrown into a form which recalls the motion of a worm. The zigzag appearance pointed out by Prevost and Dumas arises from the circumstance that when relaxation of the fibre occurs all its parts are not brought at once into the same state, but while some are contracted others are in the opposite condition. A muscle, during its contraction, appears to have nearly the same solid dimensions which it had during its relaxation. This has led to the deceptive conclusion that whatever it has lost in length it has gained in thickness. There must, however, be a diminution corresponding to the recognized amount of waste, for it is well known that destruction of a portion of its tissue is the essential condition of the activity of a muscle. The various degrees of energy with which the contraction takes place at different times is to be explained not so much by the more or less energetic shortening of the cells as by the varying number of fibres which are simultaneously contracting, or by the different fractional portion of each which is going into action at once. As the muscular effect is more energetic, so will the sense of fatigue be more speedy, for while one fibre is acting another is resting, and the same remark applies to different parts of even the same fibre. It is to this reciprocation of motion that the sound usually emitted while the muscle is in action, a low ringing sound, is to be attributed.

Muscle attached to bone by tendon.

Striated muscle is often attached to bone, or other substance on which it has to exert its mechanical power, by intervening fibrous tissue constituting tendon. These fibres are collected in groups, so as to present primary, secondary, and tertiary fasciculi. The tendinous fibres are brought in relation with the sarcolemma, and thus form a sheath connected with adjacent ones by other detached fibres. These may be considered as converging from all parts of the muscle to its extremities, and thus giving rise to its tendon. In some instances the muscular fibres attach themselves to the side of the tendon, which does not then undergo subdivision.

Fig. 226.

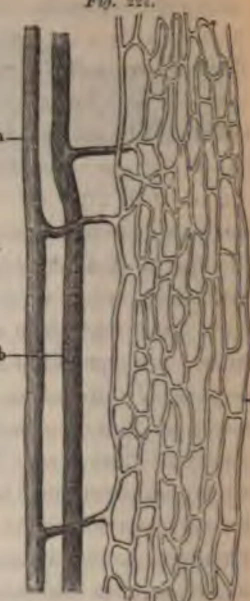
Distribution of muscular capillaries.

From the peculiar structure of muscular tissue, the capillary vessels which are distributed to it must run in a direction for the most part parallel to its fibres, as in *Fig.* 226. Their mode of branching, transverse and longitudinal,

is shown in *Fig.* 227, *a* being the artery, *b* the vein, *c*, capillary plexus. Each arterial branch has usually two venæ comites, and the supply of these capillaries has a general correspondence to the number of fibrils. The lymphatics are not numerous. Vascular distribution to the tendons is much more sparing. By the muscular blood-vessels a triple function has to be discharged: they furnish oxidized blood, on which the action of the muscle depends; they remove the waste which arises as the consequence of that activity; they also repair that waste by presenting the elements of nutrition. The younger Liebig has demonstrated that a muscle can not contract except it be furnished with oxygen, and that, as long as the capacity for contraction continues, it absorbs oxygen and yields carbonic acid.

Distribution of blood-vessels to muscle.

Fig. 227.



Muscular arteries and veins.

In the same general manner that the blood-vessels are distributed, so likewise are the nerves. An example of this is seen in *Fig.* 228. They never penetrate the sarcolemma, but run in close contiguity with it, their distribution to different parts of the fasciculi being very unequal, some parts being quite scantily furnished, the nerve filaments coming in contact, as it were, at occasional points. The opinion is generally maintained among physiologists that the nerves present toward their extremities a looped arrangement, as shown in *Fig.* 228, but by some it is asserted that the termination is in an extremely delicate point, or bifid, or trifid, without exhibiting any return. Of the two forms of muscular tissue, the striated is, for the most part, supplied from the cerebro-spinal system, the non-striated from the sympathetic.

Distribution of nerves to muscle.

Fig. 228.

Distribution of muscular nerves.

The manner of development of muscular fasciculus seems to be, that the sarcolemma is first produced as a thin and delicate tube by the coalescence of cells arranged linearly, the walls of which, where they come in contact at the ends, are obliterated, giving origin to

Development of muscle.

an elongated band. A granular material then occupies the interior of the tube. Viewing the sarcolemma as the sum of the coalesced cell walls, the fibrils are to be regarded as a development from the granular cell contents. They form, by a sort of endogenous process, from without to within. The nuclei, as has already been remarked, are on the inner surface of the sarcolemma, and not within the cells. The structure is not evident until after the end of the second month of fœtal life, but by the fourth month it has so much advanced that the muscle assumes a pale red aspect; the tendons, which have already begun to be distinctly differentiated, are gray. At birth the structure has become so far completed that the fibres can be isolated. The condition which the non-striated fibre presents is, therefore, that beyond which the striated fibre has passed, and in this respect the former may be regarded as an embryonic state of the latter. In some insect muscles an instructive intermediate condition is seen; fibres may be found striated toward the middle, and non-striated at the ends, as though imperfectly developed. The thoracic muscles of insects, which offer a beautiful example of muscular structure, are not, however, to be regarded as presenting primitive fibrils, but rather non-fibrillated primitive bundles. This I consider to be the case with the specimens from which the photographs, *Figs.* 221, 222, were taken. Though not so apparent, nuclei exist in the striated fibre even of adult life, and discharge an active function. At this period, the increase of thickness of the muscles is to be attributed to an increase in the number of the contained fibrils, which individually have about the same dimensions as before birth.

Composition of Ox Muscle.

	Berzelius.	Braconnot.	Marchand.
Water	771.70	770.30	766.00
Fibrin, cells, vessels, and nerves	177.00	181.80	180.00
Albumen and hæmato-globulin	22.00	27.00	25.00
Alcohol extract and salts	18.00	19.40	17.00
Water extract and salts	10.50	11.50	11.00
Phosphates of lime and albumen	00.80	......	1.00
	1000.00	1010.00	1000.00

Composition of Human Muscle.

	Marchand.	L'Heritier.
Water and loss	780.00	771.00
Matter insoluble in cold water	170.00	158.00
Soluble albumen and coloring matter	23.00	34.00
Alcohol extract with salts	16.00	12.00
Water extract with salts	10.00	25.00
Phosphate of lime with albumen	1.00	....
	1000.00	1000.00

The result of the chemical change which muscular fibre undergoes during the periods of its activity is eventually manifested by the appearance of carbonic acid and urea, and also salts of sulphuric acid, the two latter escaping from the system through the uri-

Chemical change during activity of muscle.

nary apparatus; the former, in part, through the lungs. That these products are to be attributed to muscular waste is inferred from their increase or diminution with increases or diminutions of muscular exertion. In the voluntary fibres there is commonly a necessity for repose, during which repair of the waste is taking place; but in those organs which are in ceaseless action, as the heart and diaphragm, the repair or nutrition goes forward at an equal rate with the waste, and no period of rest is required. It necessarily happens, during the destruction of this tissue by the arterial blood, that a rise of temperature must ensue, and such a rise has been actually observed to the amount of a degree or more, notwithstanding the constant tendency to the removal of the heat by the constant current of venous blood flowing from the muscle. There is no necessity to attribute the elevation of temperature to friction among muscular fibres, and, indeed, the amount that could arise in that way must be very insignificant, and not to be for a moment compared with that due to the oxidation. Even in muscles which have been removed from the body, and made to contract by the aid of magneto-electric currents, changes of composition may be detected.

Rise of temperature in muscular action.

OF THE FUNCTION OF MUSCULAR FIBRE.

The mechanical action of muscular fibre depends, as we have seen, on the shortening of the long axis of the cells of which the fibres are composed. To this result the designation of contractility is given, and the property by which the fibre is enabled to exhibit this shortening is designated, agreeably to the metaphysical system of the old physiologists, who were content to accept a word as an explanation of a fact, by the term irritability; this, as being useless, may be discarded; the former we may continue to employ.

Nature of contractility.

At one time it was supposed that the contraction of a muscular fibre depends so completely upon the agency of the nervous system that it might be considered as the direct function thereof; but a more critical examination of the circumstances of the shortening of the fibre cells shows that it possesses many features in common with the same contraction of the cells of plants, which have no nervous system. The influence passing along the nerve fibrils is only one out of many which can cause muscular contraction. There is abundant evidence in support of the position that contractility is the result of the structure of the muscular fibre, and that it belongs to it, and is not a special function of nerves.

Contractility not dependent on the nerves.

When muscular fibres are touched by a pointed instrument, they exhibit contraction even after they have been detached from the body, *provided that* too long a period of time has not elapsed. If it be of the stria-

ted variety, the bundle that has been disturbed alone contracts, and presently after relaxes; but there is no lateral spread or diffusion of the effect to adjacent bundles, except in the case of the heart, in which it would appear that the contraction of one part is diffused laterally, and a single disturbance is followed by many alternating contractions and relaxations, simulating, as it were, the normal function of the whole organ. But where the non-striated form is in like manner examined, the contraction takes place more slowly, spreads laterally to a wider extent, and is followed by a relaxation. The effect of an intermitting magneto-electric current is different in the two forms of tissue, the striated contracting and keeping contracted as long as the action is kept up, but the effect ceasing when the current stops. In the non-striated the action is tardy, and relaxations may ensue even while the current is passing, and contractions continue to occur after it has stopped. The effect becomes of more interest when a weak, continuous electrical current is passed through the centrifugal nerves supplying any muscle, for then the whole muscle contracts, and remains in that state as long as the current flows. If the current be passed through the ganglionic centre of those nerves contraction again ensues, and is maintained for a time even after the current has ceased. If the current be sent through the centripetal fibre, alternate contractions and relaxations of the muscle are the result. The interpretation of these different cases has already been given (p. 276).

Difference in the contractions of striated and non-striated muscles.

Effect of electrical currents.

The capability of contracting continues in muscle fibre for a certain time after death, a period which is shorter as the rate of respiration is higher, and hence these effects were first observed by Galvani and others in the case of the frog and cold-blooded animals. Even after it has disappeared, it may be re-established by continuing the supply of arterial blood, as Dr. Brown-Sequard has shown: a fact which illustrates in a striking manner the independence of the muscular contraction of the nervous system. Of course, as would have been expected, whatever interferes with due arterialization interferes with muscular power. This is the reason of the inability for exertion which is experienced in the thin air of mountain tops, the relaxation of the muscular system in asphyxia, the same condition in the respiration of the vapors of ether or of chloroform; it is also to a great extent the cause of the wayward and staggering gait of the drunkard. The converse of this likewise holds good: the higher the rate of respiration, the more energetic the muscular power; and therefore, in birds, which respire most perfectly, muscular contractility is exhibited with the greatest energy.

Experiments of Galvani.

Experiments of Brown-Sequard.

The contractility of the muscular tissues, as being independent of the activity of the nervous system, is well illustrated by the remarkable ob-

Experiments of Dr. Dowler.

servations of Dr. Dowler, of New Orleans, on the automatic movements that sometimes take place after death by yellow fever. After respiration had ceased, each hand in succession was carried to the throat, and then to the crown of the head, and so back again to the breast. In another instance, on being stimulated by a blow, the arm was extended upward, and the hand could even be made to slap the mouth; or when the leg hung down, if the flexors of the hamstring were struck, the heel was drawn upward. These manifestations continued for between three and four hours, and even occurred in amputated limbs.

Duration of contractility.

Contractility lasts for a different period, not only in different animals, but even in different parts of the same animal. Thus, in man, it declines in the following order: in the left ventricle first, then in the intestines and stomach, the urinary bladder, right ventricle, œsophagus, iris, in the voluntary muscles of the trunk, lower and upper extremities, and, finally, in the left and right auricle of the heart.

Distance at which a muscle may be influenced by a nerve.

Assuming that the diameter of each muscular fibre is, on an average, the $\frac{1}{10000}$ of an inch, and that each fasciculus is the $\frac{1}{400}$ of an inch, it may be inferred that each fasciculus contains about 650 fibres. Now, since the nerves do not penetrate the sarcolemma, the influence which they exhibit must be efficacious at a distance; and if we take the maximum measurements which have been made of muscular fasciculus, we may safely conclude that that influence extends at least through a distance of $\frac{1}{400}$ part of an inch.

The doctrine that muscular contraction results from muscular disintegration.

It is not necessary for us, in this place, to enter on a discussion of the functions of nerve fibres, whether they exert a magnetic agency, or act by rise of temperature, or, from an abrupt polar termination deprived of its white substance of Schwann permit the escape of their current into the muscle fibril, and thence into the corresponding denuded pole of a centripetal nerve beyond, the current being determined through the muscle by reason of the better conducting power of that structure. The immediate cause of muscular contraction is to be sought for in the muscles themselves, and this, I think, is much more obvious than is generally supposed. So far from there being any thing mysterious or incomprehensible about it, as some writers insist, we probably shall not be very far from the truth if we assert that *muscular contraction is the necessary physical result of muscular disintegration*, and without here considering the various ways by which that muscular disintegration may be brought about, such is the doctrine that I now present.

Change in muscle after contraction.

Reviewing the various conditions under which contraction occurs, I regard destructive metamorphosis as the primary and leading one. Every thing seems to indicate that the contraction of a fibril can not take place without the loss of a part of its

substance, and this ensues even in the artificial motions that are established by electric currents in amputated muscles, as is satisfactorily shown by the experiments of Helmholtz. Of these the following synopsis is given by Dr. Day:

"Powerful muscular contractions were induced by passing an electric current through the amputated leg of a frog as long as convulsions continued to be manifested. The flesh of both legs was then analyzed. The albumen was apparently scarcely affected, the mean of six experiments giving 210 per 10,000 of albumen in the electrized, and 213 in the non-electrized flesh. With regard to the extractive matters, it appeared that in all the experiments, without a single exception, the water extract in the electrized flesh was diminished, while on the other the spirit and alcohol extracts were increased. The results are expressed in the following tables:

Change in Muscle after Electric Contraction.

Alcohol extract from 100 parts recent frog's flesh.

<table>
<tr><th>Exp.</th><th colspan="3">a. In electrized portion.</th><th colspan="2">b. In non-electrized portion.</th><th>a : b</th></tr>
<tr><td>1</td><td colspan="3">0.752</td><td colspan="2">0.606</td><td>1.24 : 1</td></tr>
<tr><td>2</td><td colspan="3">0.569</td><td colspan="2">0.427</td><td>1.33 : 1</td></tr>
<tr><td>3</td><td colspan="3">0.664</td><td colspan="2">0.481</td><td>1.38 : 1</td></tr>
<tr><td>4</td><td colspan="3">0.652</td><td colspan="2">0.493</td><td>1.32 : 1</td></tr>
<tr><td>5</td><td colspan="3">0.575</td><td colspan="2">0.433</td><td>1.33 : 1</td></tr>
<tr><td></td><td colspan="6">Extracted with alcohol of 95 per cent.</td></tr>
<tr><td>6</td><td colspan="3">1.020</td><td colspan="2">0.748</td><td>1.36 : 1</td></tr>
<tr><td></td><td colspan="3">Water extract.</td><td colspan="3">Spirit extract.</td></tr>
<tr><td></td><td>a.</td><td>b.</td><td>a : b</td><td>a.</td><td>b.</td><td>a : b</td></tr>
<tr><td>7</td><td>1.21</td><td>1.63</td><td>0.79 : 1</td><td>1.69</td><td>1.50</td><td>1.13 : 1</td></tr>
<tr><td>8</td><td>0.93</td><td>1.23</td><td>0.76 : 1</td><td>1.65</td><td>1.35</td><td>1.22 : 1</td></tr>
<tr><td>9</td><td>0.72</td><td>0.90</td><td>0.80 : 1</td><td>1.76</td><td>1.53</td><td>1.15 : 1</td></tr>
<tr><td>Mean</td><td>0.95</td><td>1.25</td><td>0.78 : 1</td><td>1.70</td><td>1.46</td><td>1.16 : 1</td></tr>
</table>

"The amount of fat was unaffected. No urea could be found in the alcohol extract.

"There is great difficulty in performing experiments of this nature on warm-blooded animals, in consequence of the rapidity with which isolated portions of the muscle lose their contractility.

"The best results were obtained with decapitated pigeons:

	a. In electrized muscle.	b. In non-electrized muscle.	a : b
Albumen	2.04	2.13	— : —
Water extract	0.64	0.73	.88 : 1
Spirit extract.	1.68	1.58	1.06 : 1

"The above facts sufficiently show that muscular action is always accompanied by a chemical change in the composition of the acting muscle." It appears that after electrization the alcohol extract increases between 24 and 38 per cent.; the water extract diminishes between 24 and 20 per cent.; the spirit extract increases between 13 and 22 per cent.

I therefore regard disintegration of the muscular structure as the primitive act, so far as the fibril itself is concerned, and contraction as the

Balanced state of a muscle through waste and repair.

necessary consequence, that disintegration being brought about by the oxidizing agency of arterial blood. It must, however, be borne in mind that this waste is masked by its incessant repair, and that its condition at any moment of its action represents the actual balancing at that instant of the waste and repair respectively; and since the repair does not proceed with the same rapidity as the destruction, it needs must follow that, sooner or later, a point will be arrived at when there is an absolute necessity for repose to give to the renovating processes the opportunity or time for effecting a complete restoration.

Manner in which contraction occurs.

Accepting, therefore, the fact that a fibre can not contract without loss of its substance, and regarding that loss as the cause and the contraction as the effect, it is plain that whatever influence can accomplish an oxidation will produce a shortening of the fibre. Perhaps it may be that the nerve tubule does it by occasioning a rise of temperature; perhaps it may be, if nerves do not end in loops, but in denuded points, by the current escaping into the muscle from those points, and occasioning such an allotropic change in the contents of the muscle cells as enables the blood to destroy them, in the manner set forth in Chapter X. With such theories we need not now embarrass ourselves, but confine our attention to the result with which we are concerned, that is to say, the destruction of the material contained in the muscle cells, which destruction is practically brought about by the access of arterial blood. When this takes place, the cell affected undergoes an actual diminution of size, through loss of part of its contained material, its longer axis shortening from no other cause than the cohesion of its included granules thus suddenly brought into play. The cell which we have under consideration, like an entire muscular fasciculus,

Restoration of the contracted cell.

possesses no power of active dilatation, and so remains without change until it is stretched by similar contractions taking place in the components of other and perhaps distant antagonist muscles. Coincident, however, with this destruction of its interior substance, and loss of its prolate form, is the act of repair, the nucleus of the cell reproducing other granules from materials furnished by the blood; for the arterial capillaries not only bring the means of oxidation, but they bring the plastic elements of nutrition, and so permit the cell to recover its dimensions, and to be stretched to its original shape by the contraction of antagonist fibres. The destruction was almost instantaneous; the repair is an affair of a little longer time, and thus, while one part is resting, other portions of the muscular mass take up the action in succession, one after another contracting. Such is the first series of changes; let us now examine the second.

For, as the result of that first stage, there has been a liberation of prod-

ucts of oxidation, which are eventually to find their way into the urinary secretion, or to escape by the respiratory surfaces. It is immaterial what the first aspect of these substances may be, creatine, urea, extractive, etc.; this much is absolutely certain, that they are on the downward career, and will end as urea, sulphuric, carbonic acids, etc. The experiments both of Reymond and Liebig prove that the muscles, when at rest, contain no acid juice, and during their activity it is known that the degree of acidity is proportional to the energy with which they have been contracting. It can not for a moment be supposed that this acidity is the cause of the contraction; on the contrary, it is its result.

Products of muscular waste.

Among the products arising during muscular action may be more particularly mentioned inosite, or muscle sugar, which is isomeric with glucose, and creatine, which, though it contains so large a proportion of nitrogen, must be regarded as a product of the waste going on. By the loss of two atoms of the element of water, it gives origin to creatinine, which is accordingly found in the muscle juice, the blood, and the urine. Indeed, these two substances seem to be inversely proportional to each other.

Inosite and creatine.

The partial oxidation which has given rise to these various products can not occur without an elevation of temperature. A second stage of the process of muscular action consists in the removal of the heat and of the partially oxidized bodies.

We have only to look at the minute anatomy of the parts under consideration to recognize the manner in which this double removal is accomplished. The arterial capillaries, when they break up for their final distribution, run parallel with the muscular fibres, as also do the attendant veins. From one to the other, at short intervals, as seen in *Fig.* 227, intercommunicating vessels transversely pass, the whole being arranged on such a system as to afford the readiest means of removal of the blood as fast as it becomes venous —a facility of removal of the last importance for carrying off the wasted products of oxidation; and in this manner, those products, whatever they may in the first instance be, find a ready means of escape, and so the muscular fibre by degrees is relieved from these results of functional activity.

Removal of the heat and oxidized bodies by the blood.

As for the heat which has arisen in a secondary way from the metamorphosis which has been going on in the fibre, that is in like manner extracted.. It is difficult to conceive of a more effective method by which the heat could be taken away from the wasted fibre, or indeed we might say from the interior of the whole mass of the muscle. The current of venous blood bears away with it not only the products that have arisen in the oxidation, but likewise the heat.

It is probable that one cause of cessation of muscular contraction in any one point of a fibre is the momentary accumulation of wasted material, as might be illustrated in a coarse manner by the difficulty of causing a fire to continue burning when the ashes are permitted to accumulate, and the necessity of their removal before the combustion can go on. Two separate events have to occur before a fibril that has been in contraction is ready to contract again: these are the removal of the oxidized products, and the renovation of the interior of the cells. The two probably go on coincidently, the veins taking one part of the duty, and the arterial capillaries the other.

Effect of accumulation of wasted material.

In non-striated muscular fibre, in which the supply of blood-vessels is much less copious, there is a possibility for a lateral propagation of effect, because of the possibility of the lateral propagation of the heat, either supplied directly from the nerve tubule or arising from the oxidation going on. The sluggishness of its first contraction, the longer continuance, the propagation from fibre to fibre laterally until the effect wears out or is re-enforced by some new stimulus, might almost seem to be the necessary result of the imperfect supply of arterial blood, the sluggish removal of the products of waste, and the more perfect opportunity for the diffusion of heat. This doctrine therefore meets with a very happy illustration in the phenomenon displayed by the contraction of the two kinds of fibre.

Peculiarity in the contraction of non-striated fibre.

It may still farther illustrate these views to examine that other variety of contraction, rhythmic in its nature, which is exhibited, for example, by the heart, of which it may be said that the fibres show a simultaneous contraction alternating with periods of repose, contraction and relaxation succeeding each other at definite intervals. If, as we have just said, the cessation of contractility arises from the momentary accumulation of products of waste, and the capacity for its renewal is due to restoration of the original state by nutrition, rhythmic action may follow as the consequence of an arrangement of muscular fibrils with an adjusted supply of arterial and venous capillaries. An original excitation producing a contraction can not act in a permanent way, for the result of that contraction is an accumulation of wasted material which must be removed. It may require but a moment for the removal to take place to a sufficient extent to enable the original disturbance to act once more, and be checked in its action again. Whatever value there may be in such explanations as these, they undoubtedly gather a deep interest from thus enabling us to comprehend that it is possible to resolve such mysterious phenomena as rhythmic periodicities into the results of ordinary mechanical laws.

Rhythmic contractions.

But the question returns upon us. Admitting the descriptions that *have now* been given to be a true representation of the facts, and also of

Possibility of extensive muscular contraction by slight muscular waste.

their natural sequence, what is the actual physical cause of the shortening of the muscular fibril? All that we have thus far said can be received at the best as only a statement of a succession or order of facts. To say that that shortening is the direct consequence of loss of material involves us at once in the inquiry whether it be possible, through the destruction of so small an amount of material as we know to occur, that any thing like the required extent of motion could be produced. Could a muscle be made to shorten several inches, and, upon these principles, lose only an insignificant amount of weight, the shortening being nevertheless the consequence of that loss of weight or destruction of substance? To answer this inquiry, we have, in the first place, to recall the fact that a whole muscle is never in contraction at once, but only an insignificant portion thereof, one bundle of fibrils after another taking up the action in succession, and each particular fibril undergoing change, not throughout its whole length, but only in isolated portions here and there. We have, moreover, to recall the insignificant weight of these fibrils, for a simple computation will show that thirty thousand of them a foot long weigh only a single grain. To these recollections we should add the intense energy of the molecular force of attraction, as displayed at such distances as those which we have here under consideration—distances which we may regard as being virtually inappreciable, and these recollections place the problem in its true light, and set it in its proper attitude before us.

For it is capable of demonstration that muscular contraction ensues as the direct consequence of destruction of muscular substance, and that a great linear extent of movement may be accomplished by the removal of an insignificant amount of substance. If 100,000 fibrils lost one third of their entire substance—a thing which, of course, could scarcely take place—the diminution of weight would only amount to a single grain. Our conception of this action may perhaps be rendered clearer by an illustration. If we had an iron thread of excessive tenuity, composed, for instance, of a single row of iron atoms set end to end, and could, by suitable processes, effect the removal, here and there, of atoms in the line, an instantaneous contraction would be the result, the thread shortening in proportion to the number of atoms removed, but shortening with an energy commensurate with the cohesive force of the iron itself, and yet ready to return to its original length the moment that fresh iron atoms present themselves to be introduced in the place of the abstracted ones; and so with muscular fibre, the molecular force of cohesion developed here and there by the removal of tissue is to be measured only by the cohesion of the fibre, though the loss of material which may have been the cause of that force coming into play may be very small indeed; nor does the quickness of relaxation present any

Illustration of the contraction of a muscle fibre.

difficulty when we consider the rapidity with which interstitial nutrition takes place, and the small quantity of matter to be supplied.

General statement of this doctrine.

We have now analyzed the phenomenon of muscular contraction, and set forth the conditions on which it depends. These we may here reproduce together for the more distinct continuation of the argument. The primary act is the destruction of the muscular material by the agency of arterial blood; an incipient oxidation setting in, the wasting particles can no longer retain the places they have occupied. They have lost their hold on the particles with which they were associated. At that instant molecular attraction comes into play, and shortening of the fibre is the result. The wasted material is already being absorbed by the venous capillaries, and already repair is taking place by the introduction of new fibrinous material from the arterial blood; but the renewal or repair proceeds much more slowly than the removal of the waste; the latter effect, as might be inferred from what has been said under the head of absorption, occurs almost instantly, the former gradually; and thus muscular contraction presents itself as a composite result, depending, under normal circumstances, partly on oxidation, partly on removal of waste, partly on repair by nutrition, yet so that if any one of these conditions be interfered with it can not take place at all.

Volume of a muscle after contraction.

I can not at this point avoid offering a criticism on the experiments by which it has been attempted to prove that a muscle, when it contracts, loses none of its bulk; the loss that does in reality occur is, it is true, very minute, perhaps so minute that, in the coarse apparatus which has been resorted to in these experiments, it would be altogether inappreciable. Such a contrivance is represented in *Fig.* 229, in which *a*, *a* is a wide tube for containing the muscle, *g*; it is also to be filled with water, and from its side a narrow tube, *d*, projects, the water reaching to some such point as *e*. The tube, *a*, *a*, being closed at both its extremities water-tight by means of corks, *b*, *c*, whenever the muscle is made to contract by an electric current, applied by means of the spring wires, *f*, *f*, or otherwise, if enlargement occurred the water would rise at *e*, and if diminution it would descend; but as, upon trial, it is found that no movement whatever takes place, it has been inferred that the volume of the muscle remains unchanged. But no compensation whatever for temperature is provided! Yet it is positively known that when a muscle contracts it becomes warm, and, doubtless, these instruments, if delicate enough, would have led to the preposterous conclusion that a muscle after contraction is larger than it was

Fig. 229.

Volume of contracting muscle.

before. But, even setting disturbances of temperature aside, such experiments are of no kind of value, since they contain no provision for the removal of the wasted material of the muscle, which still continues a part thereof, though it has become, to all intents and purposes, extraneous, and would, if in the living system, have been instantly removed by the veins.

Correctness of partial hypotheses.

And now, by the aid of these doctrines, we may comprehend the full significance of those conditions, which have been long known to physiologists, which have cast such a mystery over muscular contraction, and led to such a diversity of views as respects its true explanation. We see that they were right who asserted that muscular contraction is a function of nutrition, though they were wrong in saying that it is therefore of a vital, and consequently of an inexplicable nature. They, too, were right who asserted that muscular contraction depends on respiration, and that the higher the rate of that function the more energetic the muscular power will be. They, too, were right who asserted that muscular contraction is manifested by a waste of tissue, and that that waste may be measured, if certain corrections are applied, by the quantity of urea and sulphuric acid in the urine. They, too, were right who asserted that there is a connection between the coagulability of the blood and the energy of muscular contraction in the various tribes of life, for the speed of repair depends on the percentage of fibrin in the blood, and so, too, does the speed of coagulation. They, too, were right who asserted the connection between muscular contraction and the speed or slowness of the circulation of the blood. All these, and many other partial hypotheses, are the necessary consequences of the more general doctrine, that muscular contraction is the result of loss of muscular substance.

Contraction produced by water.

There remains a phenomenon to which our attention has to be directed in the conclusion of this subject. It is the contractions which may be observed under the microscope when a fasciculus is submitted to water. These contractions commence in isolated places, from which they spread in all directions, and so move about from end to end, often interfering with one another, the fasciculus thickening where the contraction is greatest, and eventually the whole length becoming involved. The ultimate degree of contraction that can be reached reduces the fasciculus to one third of its original length. With this contraction, through the agency of water or other such liquids, we may connect those contractions which ensue under the pressure or disturbance of some hard body, as by the touch of a pin.

From these cases it might be supposed that muscular contractility can take place independently of chemical destruction, but a more critical examination of them will satisfy us that they ensue as the natural conse-

quences of the preceding views. They are not to be regarded as pure or uncomplicated manifestations of the qualities of muscular fibre itself, but as the consequences of the impression that has been made upon it by the treatment through which it has passed. The preparation of a fasciculus can not be made without cutting or rending the parts, mutilating the nerves of supply, and totally destroying the functions of the arteries and veins. In the act of exsecting such a fasciculus, the disturbance impressed upon it, however great it may be, is never fully answered to by the due amount of contraction; for with the destruction of the vascular mechanism there are no means of removing the products of waste, and contraction can not go on to its full completion, but in this condition the fasciculus, placed in water, gradually gives up here and there the products of waste, and with their removal the opportunity arises for the remaining muscular elements to approach one another, and, finally, complete contraction ensues; a contraction not due to the immediate action of the water, but to the change impressed upon the fasciculus by the operation for its exsection.

Contraction by touch.

So as regards disturbance by the touch of foreign bodies, we might recall those numerous instances known in chemistry, in which decompositions or other mechanical results are brought about in a similar way. The different compounds which undergo explosive decomposition by the lightest friction might furnish us with illustrations; but, in this instance, the effect is more purely mechanical, and arises from the forced equilibrium into which the fasciculus has fallen by the act of exsecting it being more or less perfectly overcome. The elements of a part of a fasciculus are brought by that touch within a nearer range of one another, the products of waste which had failed to escape because of the destruction of the absorbent function of the veins are pressed aside, one motion gives rise to another, a worm-like action spreads here and there irregularly through the length, and ends in a final contraction.

Rigor mortis.

Connected with the phenomena described in the preceding paragraph is that general rigidity of the muscles which occurs a certain time after death, and hence known as rigor mortis. This usually commences in the lower jaw and neck, invading next the upper extremities, and reaching eventually the lower ones. After continuing for a period longer in proportion to the lateness of its beginning, relaxation ensues, the parts being affected in the same order as they were made rigid. The rigor mortis sometimes begins as soon as ten minutes after death, sometimes it is postponed as long as seven hours. In those who have died of chronic diseases it occurs and ceases very quickly. Both classes of muscles, striped and unstriped, are affected by it, and when it is over they present an unresisting and lax condition, and putrefactive *change* presently sets in. Even after cadaveric rigidity has been as-

sumed, the contractile power of muscles may be restored by furnishing them, through a suitable arrangement, arterial blood; for this fact we are indebted to Dr. Brown-Sequard, his experiments having been made both upon man and animals. The arterial blood employed assumed, during its passage through the limb which was the subject of the trial, the venous character, and issued of a dark color. This restoration of contractility was by no means imperfect or transient; in one instance it continued for two hours.

By means of tendon the muscles are attached to the skeleton, which constitutes the solid framework of the system. Operating thus through the skeleton, the muscles are enabled to keep the entire body in the erect or standing position, and also to give it locomotion. The conditions of standing and locomotion have been well studied by the brothers Weber, the following being a brief synopsis of their statements.

Connection of muscle for locomotion.

In man, the power of standing implies the conservation of the line of direction of the whole body within the narrow basis covered by the feet and between them. The head is balanced on the atlas so nearly under its centre of gravity that no ligamentum nuchæ is required, as in the case of other animals, to prevent it from falling forward. Nevertheless, a forward motion can be executed, amounting to about 75 degrees from the perpendicular, and a lateral motion right and left of from 45 to 50 degrees. In standing, the weight of the entire body is transmitted perpendicularly to the feet. These rest on the heel and the fore ends of the metatarsal bones, especially of the great and little toes, and on the points of the toes. The general centre of gravity of the entire body is a little above the transverse axis connecting the heads of the thigh bones, and for equilibrium to be maintained, a perpendicular line drawn from this centre must always fall within the basis inclosed by the contour of the feet.

Of standing.

Even in the most perfect condition of rest that we can assume while maintaining the standing position, a great many separate muscular acts are necessarily required. Apart from those little voluntary changes which are incessantly occurring, the rhythmic action of the muscles involved in respiration, especially those of the abdominal walls, is perpetually changing the position of the centre of gravity, and therefore those muscles which are employed in keeping the spine erect are obliged to assume an antagonizing rhythmic action. This is at once the reason of the fatigue we experience in long standing, and of the difficulty which infants encounter in their attempts to maintain the erect position.

In walking, the legs act like a pair of pendulums. The head of the thigh bone, which is their centre of motion, is held in its socket, not by muscular exertion, nor by its ligamentous arrange-

Of walking.

ments, but by the pressure of the air, a fact that may be proved by very simple experiments. If the pressure of the air be removed, as in an exhausted receiver, spontaneous dislocation ensues. The trunk of the body is like a rod balanced on an axis passing through the hip joints, and advancing with the movement of the legs like a rod balanced on the tip of the finger. It is inclined forward or backward in correspondence with the motion or with the resistance of the wind; if the wind blows in front, we lean forward; if behind, we lean backward; the angle of inclination being in proportion to its force. In walking there are two distinct periods: the body is first poised on one of the limbs, and then rests for a moment on both. The advancing limb swings like a pendulum, bending at the knee so as to be shortened one ninth; the other straightening at the knee and hip joint, and so pushing the pelvis and trunk forward to be received on the limb that has just advanced. It is only in slow walking that the whole arc of motion is swung through, the time occupied being two thirds of a second. In quick walking and running only half a vibration is accomplished, and this in half a second of time. In slow walking each foot rests upon the ground one third of a second. The longest step made is half the entire span of the two extremities. To prevent swaying from side to side, the arms swing with the legs.

Of running.

In running there is a moment when both feet are off the ground at once, and the body actually projected into the air. In walking there is a moment when both feet are on the ground together, the one not being raised till the other is planted. In running the steps are, on an average, twice as long as in walking; and the number of steps made in a given time in running and walking respectively is as 3 to 2.

HUMAN PHYSIOLOGY.

BOOK SECOND.

DYNAMICAL PHYSIOLOGY.

COURSE OF LIFE.

CHAPTER I.

OF THE PRINCIPLE OF ORGANIZATION, OR PLASTIC POWER.

Remarks on the Subdivision of Physiology.
Career of an Organic Form.—Three Modes of Development.
Inquiry respecting the special Principle of Organization.—Illustration from the Growth of a Plant in Darkness and Light.—Inference respecting Plastic Power: its Nature and Properties.—Of the ordinary Growth of a Plant, and the Sources from which its Materials are derived.
Relation of all Organisms to each other.
Correction of the Doctrine of a Plastic Power, from Considerations regarding the Individuality of a Plant.—Plants are Operations, not Individuals.—Physical Illustration of this View.
Conclusion respecting the Nature of the Plastic Power: that it is a continued Manifestation of an antecedent physical Impression.

REGARDING physiology as a branch of natural philosophy, I have been led in this work to introduce the methods of considering it which are familiar to writers on mechanics; for, as there are two distinct divisions of that subject, according as we treat of the equilibrium or the motion of inorganic bodies, so likewise there must be in physiology a statical and dynamical branch, the one including the conditions of equilibrium of an organized form, the other those of its development—development being no more than its motion.

Divisions of physiology.

If we establish this subdivision in physiology, similar advantages will doubtless be obtained for this science as those which so quickly accrued to mechanics after Galileo had formally introduced the same partition therein. Moreover, in this case there are collateral reasons not applying to that. Whatever may be the views which the advance of science causes us to take of the various functions maintaining a living animal in its normal state—whatever may be the

Advantages of this division.

general conception we entertain of the nature of its equilibrium, it is scarcely possible to present the subject in a manner that will coincide with the diversified views of the profession. It is almost exclusively with statical physiology that the physician has to deal. The healthy and diseased states of the apparatus for digestion, absorption, respiration, circulation, innervation, etc., are the things with which he is concerned. It is respecting these that his mind is filled with the early prejudices of his education, and that his social necessities compel him to express with decision opinions unsuited to a close philosophical examination. He is to be pardoned for the mystification which circumstances oblige him to cast upon the subjects of his study; for resorting to the vital principle as an explanation of his difficulties; and for throwing upon the nervous system the burden of every thing for which the imperfect state of physiology does not enable him to account. He is not to be blamed that the circumstances under which he is placed compel him to appear to know more socially than he actually does know philosophically; and where, under such a false position of things, men have been spending their lives, it is not at all extraordinary that they should resist any attempt at a reformation which strikes at the very existence of the doctrines they have adopted, and to which they stand committed. The old physician must have his vital principle and his nervous agent, or he must begin the alphabet of his studies again. If, therefore, statical physiology stood alone, it must depend for its progress in the gradual removal of error and introduction of truth upon one generation of physicians succeeding another; but, fortunately, there is a circumstance which aids it in this march, for the great branch on which we are now entering presents connections and considerations of a more purely philosophical kind, free, at all events, from the entanglements of professional interests. Capable of being treated in the rigid manner of the positive sciences, and removed, by reason of the nature of the topics with which it is concerned, from the strifes of medical sectarianism, this noble subject can develop itself in silence, without disturbance and without restraint; and yet such an advance can not take place without compelling a reflected effect to ensue in statical physiology, and hastening the time when, by the united consent of all physicians, it, too, will be cleared from every mystification, and brought within the pale of exact and positive science.

Career of an organic form.

In the preceding book we have investigated the conditions of the equilibrium of the animal mechanism: in this, therefore, we have to treat of its motion or career. Indeed, we might generalize our expression, and include the vegetable along with the animal, for the two are so inseparably connected that we can not speak of the one without, at the same time, dealing with the other. Viewed as respects its motion or career, an organism presents us with the striking

fact that it passes through a definite series of changes. Commencing at first as a simple cell, to which what might be termed a momentum of development has been imparted, it assumes one form after another in succession, but is ever ready, like the moving bodies of mechanics, to obey the impulses which extraneous forces may impress upon it. Properly speaking, we can never say of an organized being that it is in a condition of rest. In truth, it is always in motion. It has a past and a future—coming from one state and going to another; and though, to use the language of mechanics, the inertia that it has at any moment must tend to continue it in the state at which it is then found, since it varies by degrees from one condition to another, we are obliged to look upon it in these variations just as we should upon an inorganic mass under similar circumstances, and, guided by the incontrovertible law of physics, that every change of motion is to be attributed to the influence of a force, we must impute its passage from state to state to the intervention of a like agency. In this respect, the career of an organic combination, in its two conditions of maintaining for a time a similarity or passing through metamorphoses, presents a general analogy to the uniform rectilinear, and to the varied motion of mechanics.

Three geometrical modes of development.

As we have just remarked, the most elementary organic combination appears to be a simple cell. This, under circumstances which we shall presently consider, may pass into development by multiplication in three different ways, geometrically distinct. Its development may be in one, two, or three dimensions—linear, superficial, or solid. As illustrations may be offered the protococcus, which is a simple cell; the linear confervæ, consisting of a row of cells which perpetually undergo terminal extension, the line becoming longer and longer as development of new cells at the end goes on; the ulvas, in which increase takes place simultaneously in length and breadth; and any of the higher forms, which grow simultaneously in length, breadth, and thickness. Whatever the manner of development may be, or whatever the condition presented as the combination passes from phase to phase, no doubt can be entertained that it takes place in consequence of the agency of forces which are acting under definite laws; and though, even in the case of organisms low in the series, a geometrical definition of their form is impossible, this is because of the imperfection of our knowledge, and is no kind of indication that there has been any irregularity or wantonness of play in the forces at work.

Inquiry into the existence of a special principle of organization.

Asserting thus in the broadest manner the influence of physical forces over development, and seeing that dynamical physiology must be committed to those conditions, and those alone, which are universally recognized in positive science, I shall proceed, in this chapter, to set forth the views we entertain respecting the

existence and nature of a special principle of organization. The conclusions at which we shall arrive, though apparently very different from what we might have expected, are the necessary consequences of the physical doctrine.

It may, perhaps, aid the reader if I give, at the outset, a synopsis of the argument. Selecting as a general illustration the familiar case of the germination of a seed and the growth of a plant, we shall investigate the results of growth, in light and darkness, with their attendant phenomena. From this we shall draw apparent evidence of the existence of a special principle of organization, or plastic power, and ascertain, in a general way, its functions; but, from an examination of the attitude in which the resulting organism stands, as respects its individuality, we shall learn to correct that view, and reach the final conclusion that that plastic power is not an agent, but a condition of things, the result or the manifestation of antecedent physical influences.

Outline of the argument.

Every living being springs from a germ. The animal and vegetable kingdoms present us with numberless forms, differing from one another in aspect, in construction, and in function; but the origin of all is the same—a cell or vesicle, which, under the influence of external circumstances, develops into a determinate shape.

Primordial cell.

A seed may be kept in a dry place for many years without undergoing any visible change, or losing its power of germination. It may be exposed to all the annual variations of temperature occurring in the different seasons; it may have the free access of atmospheric air. Its vitality is dormant; there is no attempt at evolving its parts.

But if some water be supplied, and a certain degree of dampness be thereby communicated, the seed does not fail, as soon as the temperature reaches that of a summer's day, to germinate. Under the influence of air, heat, and moisture, the embryo consumes the nourishment stored up for it in the seed, a gradual unfolding of its parts ensues, a root is put forth, a stem rises from the ground, and leaves make their appearance: so heat, air, and water have enabled the seed to become a plant.

Germination of a seed.

These physical agents are not, however, sufficient to carry the growth forward to its full extent. Another is essential: it is light; for if growth be conducted in darkness, heat, air, and water can not cause the young plant to add any thing to its substance. It is feeding on the seed. Indeed, when the experiment is carefully made, it is found that there is an actual loss of substance, the resulting plant, if dried, weighing less then than the dry seed from which it came.

Effects of sunlight.

In a dark place, then, it is possible for a seed to grow, but it grows in a certain way, and only to a certain extent. Its stem and its leaves are of a sickly yellowish hue: exposure to the sunshine soon produces a green color in these parts, and the weight of the plant increases. Growth in darkness leads to one result, and growth in the sunshine to another.

Partial inference respecting the existence of a plastic power.

From these facts it therefore might appear, from a superficial consideration of the thing, that the development of a plant depends on two distinct conditions—an innate power which resides in the germ, by the action of which the matters previously stored up in the seed by the parent plant are regrouped, and so arranged as to constitute a new organization; but this power does not extend to the obtaining of new material; it is only a power of arrangement—a PLASTIC POWER. Whatever new material is required must be furnished by a totally distinct agency, the sunlight; and just as the plastic power can not collect, the sunlight can not arrange. Each has its own sphere of duty. The one gives the substance, the other moulds it.

Consumption of light in vegetable development.

Every flowering plant, no matter how humble it may be, is, then, a representative of the action of these double influences, and, when properly considered, may well extend the views we ought to entertain of the system of nature. The supplying or furnishing agent, the light, comes from a star which is at a distance of almost a hundred millions of miles, and is the pivot of all the planetary motions. Without this extraneous, this foreign force, the whole surface of the earth would be a desolate waste, presenting no semblance of life. The leaf, the flower, the bud, the stem, the root, are all made of substance that has been given by the sun, derived, it is true, from one of the constituents of the air, but forced to take on the special state which suits the needs of the plastic power by that distant agent; and, in order for this to occur, it is plain, from mechanical considerations, that there must have been an expenditure of power, or of the acting principle itself, for light can not produce these effects without losing its own peculiar form. For the decomposition of a given weight of carbonic acid, and the formation of a given weight of gum, a fixed and invariable quantity of light is required; just as it is necessary, in moving a mass of a certain weight, to expend an equivalent and definite force. So the substance of which plant-organs consist has been brought into an available state by the consumption of a definite quantity of light—perhaps its incorporation, under some other form, in the resulting mass. It may be pent up and imprisoned in the organic structure for any imaginable time, even for centuries, but is ever ready to resume its primitive state when favorable circumstances exist. The coal-fields which furnish us with fuel are the remains of primeval forests which grew in the ultra-tropical climate of the secondary times,

and the light and heat we derive from them are the same that came from the sun in those ancient days.

Is the plastic power a universally diffused agent like the ether?

If, then, our earth does not possess in herself the power of sustaining the varied forms of vegetable life, but borrows it from an extraneous source; if light, in producing these effects, never undergoes destruction, but only modifies its state—for neither force nor matter can be annihilated, though they may be changed—what shall we say of the plastic power which we have thus assumed to reside in the germ, the co-worker with the luminous agent? Does their partnership in action indicate a resemblance in position or nature? If the one consists of motion arising in an ethereal, intangible, and weightless medium, diffused throughout the universe, may we suppose that the other is the manifestation of a similarly diffused principle? There is no necessity, as many have thought, to impute to the first-created germ a formative power for all its successors, as though whatever force or qualities they possess were originally concentrated and included in it. It is possible that countless millions of organic beings may have originated from one primordial germ, just as we see an extensive conflagration originating from a single spark.

That such a plastic principle exists has long been admitted by philosophers, both speculative and experimental. It is a doctrine which seems to have arisen in the infancy of human knowledge, and is to be met with in almost all the old Asiatic and European systems. The archeus and soul of the world of the alchemists were only the reproduction of a very ancient idea. The term "vital spark" was once something more than a mere metaphorical expression; and, indeed, there is a classic* nobleness in the thought which recognizes a universal spirit diffused every where. In different countries and by different authors, the nature and function of this principle are variously represented; imperfect conceptions of what is so significantly but briefly set forth in the opening words of the Sacred Scriptures, which plainly recognize the true conditions under which all vegetable organisms arose—formless matter, the sunlight, and a brooding spirit.

I shall continue to speak of this principle under the designation of the plastic power, because that expression points out aptly the function discharged, and to assume that all those organisms which possess the quality of converting inorganic bodies into organic structures do so under the double influence of light and of this interior principle. This, of course,

* Principio cœlum ac terras camposque liquentes,
Lucentemque globum Lunæ, Titaniaque astra,
Spiritus intus alit, totamque infusa per artus
Mens agitat molem, et magno se corpore miscet.
Inde hominum pecudumque genus vitæque volantum,
Et quæ marmoreo fert monstra sub æquore pontus.—VIRG. ÆN., l. vi., 724.

includes nearly all vegetable forms, for we may leave out of consideration the fungi, a group which stands intermediately between plants and animals. The distinctive character of a plant is to form, from carbonic acid of the air, solid organic structures. The distinctive character of an animal is, by the oxidizing processes going on in it, to restore the organic bodies which have served it as food to their original formless state. The group referred to differs from true plants in feeding on matter already organized, and breathing like animals. It therefore does not require the influence of light to collect material for it, and bring it to the proper state. In the development of this group the plastic principle is alone concerned.

Power of different colored rays of light.

Since the sunlight is composed of many differently colored rays and different principles, it becomes an interesting inquiry which of these is the immediate agent in ministering to the nutrition of plants. In 1843, by causing plants to effect the decomposition of carbonic acid in the prismatic spectrum, I found that the yellow is by far the most effective, the relative power of the various colors being as follows:

Yellow,	Blue,
Green,	Indigo,
Orange,	Violet.
Red,	

Phenomena of the action of light on the growth of plants.

My experiments on the production of hydrochloric acid by the direct union of chlorine and hydrogen under the influence of light, both artificial and solar, and also on the decomposition of peroxalate of iron, from which carbonic acid is readily disengaged, conclusively establish the fact that the primary condition essential for the chemical action of light is the absorption of some particular ray. If the physical condition of substances otherwise easily decomposable is such that they transmit light without absorbing any, no chemical change ever ensues in them, and the same condition obtains in cases of combination. Thus oxygen and hydrogen can not be made to unite, even by the most intense radiation, because neither of them exert any absorptive action; but chlorine and hydrogen unite with energy, because the chlorine absorbs the indigo ray.

The same experiments prove that the amount of decomposition or other work done by light is always proportional to its quantity; hence, by the aid of converging mirrors and lenses, chemical changes can be accomplished with great rapidity. These instruments, however, when even of the largest size, are unable to produce any other effect than would be brought about by a feebler ray if applied sufficiently long. The greatly increased intensity of light which they can present does not enable us either to bring about combinations or decompositions of substances which

are unacted upon by rays of a more moderate brilliancy, for the general rule under which the chemical action of light occurs is, the amount of chemical change is as the quantity of light absorbed.

These facts are of importance in all discussions respecting the primitive formation of organic matter by plants. Guided by them, we infer that, though vegetation may greatly differ in its luxuriance in different climates of the globe, the manner of action of the light is always the same. Nothing is gained under the brilliancy of the tropical skies beyond a shortening of the time required for the accomplishment of a given amount of work. No substances are there decomposed, even in the organisms of plants, which could not equally well be decomposed by the feebler light of more temperate climates, only in these it would demand more time. The oils and other substances, almost or quite free from oxygen, which abound in the plants of the torrid zone, are not exceptions to, but illustrations of, the doctrine here set forth.

It is not the green parts of plants which decompose carbonic acid.

It is proper here to correct the statement which is usually made by vegetable physiologists, that the decomposition of carbonic acid by plants is accomplished by their green parts. A plant which has been etiolated, or, indeed, one which has been raised from a seed in total darkness, when brought into the sunshine, decomposes carbonic acid, liberates oxygen, and its pale and sickly leaves presently turn green. This, therefore, demonstrates that the green portions are not the seat nor the origin of the decomposition, but are, properly speaking, its effect.

Plants liberate oxygen.

Thus, under the influence of sunshine, the leaves of plants decompose carbonic acid, liberate its oxygen, which, for the most part, escapes into the atmosphere, the amount of gas decomposed depending primarily on the quantity of light supplied, and therefore, among other conditions, on the surface of exposure of the leaves, and not upon their thickness or mass. But I found, on an examination of the gas thus evolved, that it is never pure oxygen, but always contains a certain though variable proportion of nitrogen. From this it follows that a part of the oxygen appertaining to the carbonic acid is appropriated for the uses of the plant.

Such, in a general way, is what takes place in the daytime, but at night the process is to a certain degree inverted, a plant absorbing oxygen from the air, and yielding carbonic acid. The explanation which Liebig offers of this state of things is doubtless correct, that the evolution of carbonic acid is a purely physical process, and the absorption of oxygen due to the chemical action of the various deoxidized bodies which have been accumulating during the day.

As respects the sources from which the various constituents of the plant organism are derived, they are sufficiently obvious. The carbon

may doubtless be entirely attributed to carbonic acid, obtained either directly from the atmosphere or furnished by the gradual decay of humus in the soil. For the hydrogen a double source may be assigned—water and ammonia. The abundant occurrence of resins, oils, fats, in which this element preponderates, conclusively establishes the fact that the supply of ammonia, as indicated by the nitrogenized compounds which have been formed, is insufficient to account for the quantity of hydrogen, and for which there would appear no other source than water; and though the most brilliant light, even though concentrated by a powerful burning-glass, can not alone effect the decomposition of this liquid, there will be no difficulty in admitting that such a decomposition does take place, when we recall that carbon is being presented in what might be termed its nascent state.

Sources from which the constituents of plants are derived. Of carbon.

Of hydrogen.

Of the nitrogen necessary for the formation of the protein bodies of plants, it is generally concluded that ammonia is the only source, and that these organisms do not directly obtain that element from the atmospheric air; moreover, it occurs apparently to a sufficient extent in their sap, having been introduced by absorption through the roots. As essential to the production of the same group of bodies, the protein substances, both sulphur and phosphorus are introduced through the same channel, from the soil, as sulphates and phosphates, which undergo decomposition and deoxidation within the organism, so as to yield the sulphur and phosphorus in an unoxidized state.

Of nitrogen.

Of sulphur and phosphorus.

We can not overlook the saline substances, or mineral bodies, which occur in different parts of plants, and which obviously are absolutely essential to their constitution. The circumstance that, in any given plant, they are found fixed in their nature, definite in their quantity, and deposited in determinate regions, is sufficient to establish that conclusion. As is very well known, we can not judge of their nature or condition during the life of the plant from the aspect they present when its ash is examined. Thus those which have been existing as neutral or acid salts of organic acids must appear in the ash as carbonates; and though it has been established that basic and mineral substances generally will to some degree replace one another—nay, that even the plant itself, by generating vegetable alkaloids, may dispense with bases of the mineral kind, the extent to which this can be carried is as yet undetermined. The occurrence of sulphates and phosphates in the leaves and seeds, and wherever organic activity has to be displayed, and protein bodies are found, is sufficient to establish a connection between those substances and the neutral nitrogenized bodies, though of the manner in which, from carbonic acid, water, ammonia,

Of saline substances.

sulphates, and phosphates, those bodies are formed, we are as yet altogether ignorant.

The decomposition of carbonic acid is not partial, but total.

By some chemists it has been supposed that the decomposition of carbonic acid by plants in the sunshine is not instantaneously complete, but that a gradual process of reduction takes place, the carbon losing by little and little its oxygen, but never, perhaps, losing it all. My own experiments, previously alluded to, which show that the quantity of oxygen set free is never quite equal to that of the carbonic acid consumed, have been used in support of this view. But this, I think, is an interpretation which they will scarcely bear. There are many facts connected with the chemical action of light which might be cited as offering abundant proof that the decomposition in question is, on the contrary, instantaneous and complete, and in that I am led to believe really consists the primary function of the light, the carbon thus obtained being subsequently employed in accomplishing the decomposition of water, and other processes of reduction known to go on in the vegetable organism, but with which, under the circumstances of the case, it is impossible that the sunlight should be directly concerned. I separate as distinct factors in the life of a plant the obtaining of carbon from the air, which is accomplished by the influence of an external agent, and the moulding or modifying it with other ingredients into organized material, which we have thus far imputed to a plastic power in the plant itself, and respecting which more will be presently said. Free carbon once obtained, we can easily conceive that all other operations of reduction may follow, and that this division of the action of plants into two distinct stages or factors, as we have just termed them, is not a mere speculation, but represents what in reality occurs, will perhaps be admitted on recalling what has been remarked on growth in the sunshine and in darkness respectively.

Summary of the action of plants on the atmosphere.

As a summary of the action of vegetation on the air, it is on all hands admitted that plants tend, by the removal of carbonic acid therefrom and the return of oxygen thereto, to compensate for the disturbance occasioned by animals, which is to the opposite effect. In this way, through very many centuries, the same percentage constitution of the atmosphere is maintained, the sum total of vegetable being automatically adjusted to the sum total of animal life; automatically, and not by any interference of Providence; for if we admit, what has been conclusively established by direct experiment, that plants would grow more luxuriantly in an atmosphere somewhat richer in carbonic acid than the existing one, we may see how upon this condition depends a principle of conservation, which must forever retain the air at its present constitution, no matter how animal life may vary. The proofs *that* are sometimes offered that there has been no change in this respect

for at least 2000 years, and which are drawn from an examination of the aerial contents of vessels said to have been obtained from Pompeii or Herculaneum, are of very little account. We have only to recollect how easily diffusion takes place through crevices, and even almost invisible pores. But there are proofs of a far higher order, and of a much more general kind, which might be brought forward, if this were the proper place, establishing beyond all possibility of contradiction the fact that in a slow manner, through countless ages, the constitution of the atmosphere has changed, and that now, through the operation of conditions which have spontaneously arisen, it has come into a condition of apparent equilibrium.

When, therefore, a seed is placed in the ground in the warm season of the year, the germ it contains develops, and, after a few days, makes its appearance as a young plant at the surface. If the growing structure is examined during its passage through the soil, it presents a pale yellowish aspect, which is exchanged for a bright green tint as soon as it escapes from its confinement, and unfolds itself to the sunlight and the air.

Infantile and adult life of plants.

From the first moment, until the green color is assumed, the young plant is nourished, as we have seen, at the expense of the seed. In anticipation of this, the parent had laid up a stock of nutritive material. On this the embryo draws, consuming a part in the support of its life, and incorporating the residue in its structure; but as soon as the surface of the soil is gained, this life of dependence ends; the plant weans itself, and, abandoning its temporary support, commences to collect from the air and the earth the materials of which it is to consist. Its infantile seed-life has closed; its independent aerial life has begun.

Summary of the conditions of growth.

In this aerial life, which is the mode of existence destined to continue until absolute death occurs, the two essential conditions to which we have drawn attention are recognized. There must be a steady supply of material for the building up of the growing structures, and this has to be derived from external sources. There must also be a capability of so grouping or moulding the material thus acquired that the various parts that are wanted—leaves or fruits, flowers or thorns, may be made.

The manner in which these conditions are satisfied presents to a reflecting mind one of the most wonderful examples of the system of nature. We have already shown that the power of moulding and grouping is inherent in the plant. In virtue of this, while it was yet in the ground, and therefore in the dark, the germ could put up its stem and fashion its imperfect leaves, but it did not possess any power to gather nourishment beyond that which was stored up in the seed, and had that stock been exhausted before it reached the surface, it must have died.

We have also shown that the supply of new material is always furnished by the sun. In the absence of his rays the plant may organize, but can not increase, and, indeed, it was to the influence of light that the green color of the first leaflets was due. All the day long, and with the more activity as the day is brighter, the leaves, which are the collecting organs, are absorbing material from the air; they cease to do it at night. The sunbeam enables them to take from the air carbon, hydrogen, and nitrogen. They feed by day and fast at night.

Astronomers say that the sun is the most sublime object the eye of man can contemplate. They speak of his prodigious mass, and describe how he compels the planets to move in obedient circles around him. To the physiologist he is not less sublime. The most insignificant moss that grows on the wall was called into existence by his heat, and is daily fed by his light. The sunbeam is the finger of God.

The nutrition of plants is therefore dependent on physical causes. The carbonic acid required being brought to them by aerial currents, occasioned partly by the warming influence of the sun on their leaves and partly by the winds, the tendency of gases to diffuse into one another aids in producing the same result. In this manner, as they exhaust the surrounding air, fresh quantities are supplied, the separation of carbon from it being brought about by the agency of the yellow rays. The leaves, also, sometimes follow the motion of the sun, or present themselves in the most favorable position under the influence of the indigo rays.

The water requisite is obtained from the soil by the spongioles of the roots. With it there are carried into the interior of the plant the saline and inorganic substances necessary for its structure. These, since they are often of sparing solubility in water, will require large quantities of that liquid to effect their introduction to a proper amount. During the course of a summer there may pass through the system of the plant perhaps many hundred times its weight of water—a prodigious amount when the phenomenon is considered on the great scale.

Relation of organisms to each other.

Cuvier speaks of the inferior organisms as furnishing us with a series of experiments made by the hand of Nature, an idea often quoted and often admired, but which is, perhaps, scarcely consistent with enlarged conceptions of the system of the world. An organism, no matter how high or low, is not in an attitude of isolation. It is connected by intimate bonds with those above and those beneath. It is no product of an experimental attempt, which, either on the part of Nature or otherwise, has ended in failure or only partial success.

The organic series—an expression which is full of significance and full of truth, for it implies the interconnection of all organic forms—the organic series is not the result of numberless creative blunders, abortive attempts, or freaks of Nature. It presents a far nobler aspect. Every

member of it, even the humblest plant, is perfect in itself. From a common origin, a simple cell, all have arisen: there is no perceptible microscopic difference between the primordial vesicle which is to produce the lowest plant, and that which is to produce the highest; but the one, under the favoring circumstances to which it has been exposed, has continued in the march of development, the career of the other has been stopped at an earlier point. The organic aspect at last assumed is the strict representation of the physical agencies which have been at work. Had these for any reason varied, that variation would at once have been expressed in the resulting form, which is, therefore, actually a geometrical embodiment of the antecedent physical conditions. For what reason is an offspring like its parent, except that it has been exposed, during development, to the same conditions as was its parent? Comparative physiology is not a fortuitous collection of experiments. Our noblest conception of it is the conception we have of analytical geometry, and, speaking in mathematical language, each member of the organic series is an embodied result of a discussion of the equation of life for one special case. Nay, I would present the whole system of Nature as included in the same idea. The inorganic and lifeless combinations which are all around us are, to my mind, in truth, in that equation of life, the analogues of the imaginary solutions of the calculus.

The forms of organization depend on physical agents.

It was a felicitous thought of Descartes that we may represent a geometrical form in an algebraical equation, and, by the proper consideration and discussion of such an expression, determine and delineate all the peculiarities of such a form; that here it should become concave and there convex, here it should run out to infinity, there have a cusp. The equation determines all the peculiarities of the form, and enables us to construct it. But if the original conditions are inconsistent with one another, the construction can not be fulfilled, it having become impossible. In the same manner are all living and lifeless forms related: an increase in the value of one condition carries development forward in one direction, and increase in the value of another condition determines development in another way, and these variations give rise in their succession to the whole organic series. But in these, as in the other case, if inconsistent conditions have existed, their presence is indicated in the resulting solution, which can not be constructed as an organic form, but is represented as a lifeless mass.

Illustration of the relation of organic forms derived from analytical geometry.

"God ever geometrizes," and, it might be added, ever materializes. Every organism is the result of the development of a vesicle under given conditions, carried out into material execution. It is the incarnation, the embodiment, the lasting register of physical influences; for, if such lan-

guage may be with propriety used, the consequences of the action of natural agents do not remain as a barren idea in the creative mind, but are presented as a material and tangible result.

Such a mathematical conception of the relations of the various forms around us obliterates at once the line of demarcation which natural history has thus far vainly attempted to define with correctness between the organic and inorganic worlds. In the system of creation no such boundary exists; neither does one exist between the vegetable and animal groups. On every form, all existing influences have exerted their sway: gravitation, heat, electricity; the result is the issue of their action. The shape of any great mountain is thus the record of every thing that has affected its mass since it was first uplifted. Its ancient peaks are the register of every summer's sun, every frost, every falling rain, every lightning stroke. It is what it is because of them; and so also of the lichen which unfolds itself on some favorable spot on the rock. Would it be there at all, or would it have the special aspect it presents, if there was not a due proportion of sunshine, a proper supply of moisture, a suitable temperature? It is such conditions which have called it forth. It is what it is because of them. In this respect, between the inorganic and organic, there is no difference.

Correction of this doctrine of a plastic power.

The preceding elementary examination of the circumstances under which plants grow has led us to the inference that in their germ there resides a plastic power whose function it is to model the organic matter, as it is furnished by the sunlight, into definite shapes or organs. We now proceed to correct the conception we have thus formed, and to show that it is more philosophical to decline the idea of an *agent* and to accept that of a *condition*.

Considerations respecting the individuality of a plant.

Perhaps the most simple method of illustrating this idea is from considerations connected with the individuality of the organisms which have thus arisen. Directing their attention to plants, botanists have occupied themselves in endeavoring to determine what is the attitude in which they stand. They have tried to find out wherein the individuality of a plant consists, for this question of individuality lies truly at the basis of the position which those structures occupy. There are oaks that have lasted a thousand years, but are they to be regarded as individuals that are a thousand years old? Is not such a tree rather like a nation, a collection or colony of individuals, the individuality belonging to each bud, to each leaf it has borne; for there is a close analogy, if not an absolute identity, between the process of development of a seed in the ground and of a bud upon a branch; both have their infantile, both their aerial life. The leaves of the oak, which expand in the spring, fall in the autumn. Their origin and duties are connected with astronomical events. Each annual generation,

while it lasted, carried forward all the functions of the tree, as, in a nation that may have endured for a thousand years, each generation of men has borne its part in the general scheme, and made provision for its successors. The individuality therefore lies not in the tree, but, perhaps, as thus far considered, should be referred to the bud.

But, moreover, when we consider the modes by which a tree may be propagated, as, for instance, in the horticultural processes of budding or grafting, our views of this question of individuality must again be modified. By these artificial operations an original stock may be multiplied again and again, and each of the plants so arising is undistinguishable from any other that may have come in the same way. Setting aside the incidental difference that, through the intervention of artificial means, the buds from which two such plants have originated have been brought under the condition of physical independence of one another, the one, perhaps, growing in America, the other in Europe, is there any absolute and essential difference between them more than there would have been had they been permitted to remain upon the parent stock, and to develop themselves into two branches thereof? Such facts suggest to us that individuality does not belong to plants, as they thus present themselves to us, and that perhaps we ought to assume an individuality of a higher order—a race individuality, as it were. In this manner, all weeping willows in Europe and in America are one individual, because they have all been derived from one original imported Babylonian stock; and the same might be said of every one of our cultivated fruits. But of these, if a seed be planted, the general aspect of the resulting growth may possibly be the same as that derived from a graft, and how shall we then make a distinction between the one and the other? for, though by seed development the plant may chance to run back to a wilder form or to produce a new variety, this result is by no means absolutely necessary.

From similar considerations, some physiologists have been led to deny individuality to the bud and the seed, and to refer it to the primary cell; but here, again, precisely the same difficulties are encountered. A cell may multiply itself by fissure through its nucleus, as well as in an endogenous way; moreover, cells arise from granular material. Individuality, therefore, except it be that of a lower order, can not be attributed to them, and the question of the determination of it rests precisely where we found it.

The idea of individuality is inapplicable to plants.

In truth, are not all such discussions, in their very nature, illusory, so long as we have no more definite idea of the term individuality? If a natural philosopher were to occupy himself with similar discussions respecting the flame of a lamp, he too, doubtless, would be led to precisely the same empty conclusion. He might show how, in such a flame, there are separate, well-marked re-

gions, some of which were present at the first moment of its existence, and remain to its end, as, for example, the blue portion which is at its under part. He might show how every one of these flames tends to assume a definite or determinate form—conical, for instance—and proceed to argue that this is the result of the interaction of external causes, as the passage of currents in the air, and some interior principle or power possessed by the flame itself. He might consider how that from one flame another can be kindled, in all respects like its parent in qualities or shape; and how, in succession, from one original, myriads upon myriads might so arise. He might engage himself in disquisitions as to the manner in which such an extraordinary result is to be explained, and as to the source to which he should impute with exactness the origin of each of these independent flames, and their mutual interrelation. He might inquire if the force which each possesses was originally contained in the original flame, and how it came to give it forth without loss of any of its own power. He might also amuse himself with questions of individuality, and, in doing all this, it would be no more than physiologists have done before. Between the case of the trees and flames, of which we have been speaking, it is not difficult to see that there is an analogy.

Plants are operations, not individuals.

Are plants, in truth, then, nothing more than temporary states through which material substance is passing, because of some original physical impression made upon it, and the present operation of external circumstances? Can individuality be applied to them any more than to a flame? Instead of being individuals, are they not rather the transitory results of an operation?

Analogy between a plant and a flame.

The lamp, which we have been using as an illustration, may serve to enlighten our path a little farther. In the infancy of chemistry, it might have been said of it that it possessed a burning power, which enabled it to dispose of the matter with which it was fed, just as we say of a plant, in the infancy of physiology, that it possesses a plastic power, which groups into definite forms the substance with which it is furnished. The so-called burning power was derived from another flame, in all respects analogous to that which manifests it, and is nothing more than an extension of a physical operation, the tendency of which, so far from being to check, is to continue as long as the proper material is furnished. The lighting of a second flame is essentially the same condition as the continued combustion in the first. The fact of separateness changes the phenomenon in no respect whatever; the relation of two separate flames is the same as that of two different parts of the same flame; and so the derivation of a plastic power by a plant from its ancestor is essentially the same thing as the manifestation of a similar power in different parts of its own system.

Though it may therefore be convenient to speak hypothetically of this

principle which accomplishes in a plant the grouping of its parts as if it were an *agent*, the foregoing illustrations show us that all the facts of the case are equally well satisfied on the supposition that it is the continuation of an *operation*. A multitude of parallel instances present themselves. In the making of leavened bread, all the phenomena would seem to be accounted for either upon the hypothesis that there resides in the leaven or ferment *an agent*, whose quality it is to determine a specific change in the flour, or that there is *an operation* which, because of the chemical *conditions* existing, is gradually spreading, and which will not cease until all the material submitted to it has been affected, and this no matter whether it be in the same mass or in successive portions. Of such hypotheses, the first is merely an elementary idea, the latter involves a philosophical conception.

Nature of the plastic power.

In this way, therefore, the so-called plastic power of a cell or the germ of a seed may be regarded as the continued manifestation of an antecedent impression long ago made, and which, under the existing conditions, has no liability to wear out or die away; and that impression may have been purely physical in its nature.

The life of plants is a physical phenomenon.

Viewed in this attitude, the life of plants is a physical phenomenon. The parts of which they are composed are furnished to them by influences of a mechanical kind: their carbon is taken by a true chemical decomposition from the carbonic acid of the air; their nitrogen comes from ammonia or from the atmosphere. Water is drawn by capillary attraction from the ground. In virtue of its chemical qualities, it carries into the growing system the various saline bodies present in the soil, and which are needful for the economy. The sunlight, heat, rain, winds, are the supplying and nurturing powers, and the grouping agencies residing in the plant are of the same mechanical derivation or order.

The germination of a seed and the growth of a plant, as thus considered, show us to what an extent physical forces are concerned in vegetable organization. The conclusion thus indicated is enforced in no common manner when we direct our attention to the series instead of to a single plant. This is what I propose to do in the following chapter.

CHAPTER II.

ON THE INFLUENCE OF PHYSICAL AGENTS ON THE ORGANIC SERIES.

Of the Geography of Plants: their horizontal and vertical Localization.—Influence of Heat on organic Distribution: isotheral and isochimenal Conditions.—Effects of Variations in the Density of the Air, Moisture, Soil, Sunlight, Length of Day.—Definite Quantity of Heat required by Plants.

Secular Perturbations in the Species of Plants.—Long Periods of Time required.—Secular geological Changes.

Inverse Problem of the Investigation of the Earth's History from her fossil Flora.—Two great terrestrial Epochs: Change in the Constitution of the Air, and Localization of Organisms through Decline of the Earth's Interior Heat.

Difference between abrupt and gradual Impressions.—Invariable Causes may produce abrupt Crises.

Extension of the above Principles to the Case of Animals.—Case of the Inca Indians.

General Argument supported by the Extinction of Forms.—Development is under the Influence of Law.—Rudimentary Organs and Excesses of Development.—The Idea of Development by Law consistent with natural Facts.

Geographical distribution of plants.

THE publication of HUMBOLDT's Essay on the Geography of Plants first formally drew the attention of botanists to the connection between the distribution of vegetables and the distribution of heat on the surface of the globe. Starting from the equator and advancing to the pole, in either hemisphere, the mean annual temperature declines as the latitude becomes greater, and in succession a series of vegetable zones, merging gradually into each other, though each, where best marked, perfectly distinguished from the succeeding, is encountered. In the tropics we have the palms, which give so striking a characteristic to the forests, the broad-leaved bananas, and the great climbing plants, which throw themselves from stem to stem like the rigging of a ship. Next follows a zone described as that of evergreen woods, in which the orange and the citron come to perfection. Beyond this, another of deciduous trees—the oak, the chestnut, and the fruit-trees with which, in this climate, we are so well acquainted, and here the great climbers of the tropics are replaced by the hop and the ivy. Still farther advancing, we pass through a belt of conifers—firs, larches, pines, and other needle-leaved trees, and these, leading through a range of birches, which become more and more stunted, introduce us to a region of mosses and saxifrages, but which at length has no tree nor shrub; and finally, as the perpetual polar ices are reached, the red snow-alga is the last trace of vegetable organization.

A similar series of facts had been observed by Tournefort in an ascent

of Mount Ararat. He found that the distribution of the vegetation from the base to the top of the mountain bore a general resemblance to the distribution from the base toward the Arctic regions. These facts by subsequent observers were generalized, it having been established that there exists an analogy between horizontal distribution on the surface of the globe and vertical distribution at different altitudes above the level of the sea. Even in the tropics, if a mountain be sufficiently high, a very short ascent suffices to carry us from the characteristic endogenous growths at its foot, in succession, through a zone of evergreens into one of deciduous trees, and this, again, into one of conifers, the vegetation declining through mosses and lichens as we reach the region of perpetual snow.

Vertical distribution of plants.

In these two cases of horizontal and vertical distribution respectively, which thus present such a striking botanical resemblance, there is likewise so clear a meteorological analogy that it is impossible to avoid coming to the conclusion that the distribution of plants depends on the distribution of heat. The same climate variation encountered on a surface journey directed from the equator toward the poles is again encountered as we leave the foot of a tropical mountain and go toward its summit; for it is a well-ascertained fact that the temperature of the atmosphere declines as we rise to greater altitudes, and that, no matter how high the summer heat may be, we may, by a vertical ascent at any locality, come to a region where the temperature is never above 32° Fahr., and where ice and snow, therefore, never melt. If, in any locality, the mountain ranges are of sufficient height to gain that region, their tops will be covered with perpetual snow. The vertical ascent thus to be made is less as the latitude is greater. At the equator it is 15,200 feet, and at the eightieth degree it is within 450 feet of the ground. Beyond this, the surface itself is perpetually frozen.

Distribution of heat determines the distribution of plants.

The mean temperature of a place determines its vegetable growth, and hence there will ever be a resemblance between the vegetation of places of the same mean temperature, though they may be geographically very wide apart. But this, though a resemblance, is very far from being an identity. We can not always designate by name the particular plants of a high latitude which should be found at a corresponding elevation in the mountains of the tropics. There may be the general resemblance of which we have been speaking, and yet the genera and species of plants in the two places may be quite distinct. But this fact, far from affecting the truth to which we have arrived of the control of a physical agent such as heat over the distribution of plants, leads us to extend it, and teaches us that, though we might expect, in places far apart, identically the same vegetable growths if

Influence of other physical conditions.

all the physical conditions were identical, yet, since heat is only one of these conditions, it alone is insufficient, and that differences in the pressure of the air, the amount of moisture, the quantity of carbonic acid, as also variations in the constitution of the soil, must have their effect. Instead, then, of limiting our views to the control of temperature over the occurrence of plants, we must enlarge them in such a way as to include divers other influences, some of which are those just mentioned, and all are equally of a physical kind.

This therefore brings before us, in an impressive manner, the subject to which this chapter is devoted, the influence of physical agents generally over organization.

That the conditions of temperature alone are insufficient to account for the occurrence and distribution of plants may be clearly established by the aid of another series of facts. Throughout the old continent, with the exception of its torrid zone, from the south of Africa to the north of Europe, heaths abound, their species being very numerous in the southern latitudes, less so in the northern, but the individuals increasing in number as the species diminish. At the extreme north the common heather remains as the sole representative of the whole group, and so universally covers the surface as to give a characteristic feature to the landscape. But in America, which reaches through all corresponding degrees of latitude, and has in its proper localities the same mean temperatures, not a single heath ever occurs. Again, in the New World, through forty degrees on each side of the equator, the cactus tribe of all kinds of grotesque forms abounds, but in Africa, though there are localities of corresponding temperature, not a single cactus is to be seen. The spurges there make their appearance. So, again, in Australia, the forests present a melancholy and shadeless character from their leafless casuarinas, acacias, and eucalypti, whereas, if temperature alone were concerned, they should offer the same aspect as the forests of North America and Europe.

Influence of the summer heats and winter colds.

Restricting our examination for the present to the influence of heat, it may be observed that this is by no means so simple as might at first appear. Its distribution does not correspond with the latitude, the lines of equal mean temperature, isothermal lines, not coinciding with the parallels of latitude. If we examine the zones of plant distribution just described, we find that they follow the isothermal lines much more closely than the latitudes; but even here, again, there are very great deviations—deviations which, however, are to some extent understood when we recall that it is not so much with the mean annual temperature that plants are concerned as with the special temperature of particular moments of the year. For the most part they are affected by the heat of the summer season, which is their period of

growth, and though two localities may have the same mean annual temperature, it does not follow that their maximum of cold for the winter, and their maximum of heat for the summer, should coincide. It was such considerations that led to the construction of isotheral lines, or those of equal summer heat, and isochimenal lines, or those of equal winter cold.

Into the causes which bring about this difference of heat distribution it is not necessary for us here to inquire minutely. They are very various. The prevalent winds at different seasons of the year, ocean currents, the geological structure of a country, even what might be termed its optical qualities, that is, its power of absorbing the rays of the sun (for instance, the great Desert of Sahara disturbs the temperature of all Europe), and upon like principles must act the removal of extensive forests, and their substitution by equivalent surfaces of cultivated, differently colored, and differently absorbing lands, elevation above the sea level, for the higher the country the lower its temperature: these, and a multitude of other such conditions, impress an effect upon the distribution of heat. The mean annual temperature represents these and all other such influences, and includes all the variations, diurnal and nocturnal, monthly and seasonal, for the year.

Causes of the irregular distribution of heat.

The organic functions of a plant demand particular temperatures at particular times. There is, doubtless, a special degree best suited to the period of germination, another to the period of aerial growth, another to the period of fertilization, and another to that of ripening the seeds; and these degrees differ in the case of different plants. Where the requirements become so complicated, it would be erroneous to expect that the mean annual temperature should satisfy them all.

Connected in part with temperature, and in part with elevation above the sea, are the variations in the density of the air. These control, to a certain extent, the aerial supply to plants, the quantity presented to their leaves diminishing as the density becomes less.

Influence of variations in the density of the air—moisture, etc.

The same observation may be made respecting moisture, which, as is very well known, constitutes one of the most influential conditions in determining the growth of plants, and this in a double way, either as vapor contained in the air or as rain. The effect of rain in this respect is twofold: it diminishes the quantity of atmospheric carbonic acid by exerting over it a solvent power, carrying it into the ground, and thereby reducing, by sometimes as much as one half, the supply on which the leaves are depending; it also brings in larger quantities to the interior of the plant the saline constituents of the soil which are requisite for tissue development.

To variations in the temperature, the density of the air, and its moist-

Influence of the soil. ure, as affecting the well-being of plants, may be added the chemical constitution of the soil upon which they grow. Lime-plants can never be developed except on soils in which that earth abundantly occurs, and the same may be said of potash or soda plants, or, in short, of any which demand some special mineral ingredient. Thus, for instance, the salsolas and salicornias, which grow abundantly on the Atlantic shores of France, and which require for their development the saline ingredients of the sea, are nowhere to be seen throughout Central Europe, though they reappear on the salt steppes of Russia, and abound around the Caspian. We should scarcely expect that sea-weeds, into the composition of which bromine and iodine abundantly enter, should ever grow in waters from which these chemical elements are totally absent. Upon these principles, the vegetation of extensive tracts of country has undergone a change in an artificial way. Thus, for instance, in Virginia and other Southern States, we may pass for miles in succession through tracts in which the ancient forest-growths have been replaced by the Pinus tæda, or old field pine. These are tracts from which the potash salts have been removed, to a great extent, by the culture of tobacco. And of the indigenous trees, this pine requires the smallest proportion of those salts. It therefore can flourish where the others can not exist.

Influence of the sun's light. From what has been said in the last chapter, it may be inferred that among the various conditions thus influencing the growth of a plant, none are of greater importance than the amount of light furnished to it. Through this agent the decomposition of carbonic acid is effected, and the plant obtains from the air the carbon it requires, out of which its solid structures are for the most part built. The rapidity with which the reduction of the carbonic acid takes place depends upon the brilliancy of the light, and the amount of carbon thus obtained upon that condition and the time of exposure conjointly. The amount of light received from the sun in any locality depends in a general way, as does the heat, upon the latitude; but in both cases a multitude of disturbing agencies intervene. Variations of moisture control the supply of light by permitting a translucency, or establishing its opposite, a cloudiness or murkiness of the air. Other meteorological causes, as, for example, winds, by condensing or removing moisture, act in like manner; so also do astronomical conditions, especially by influencing the relative length of the day and night; for, as we advance toward the pole, the summer sun is above the horizon longer and longer. In Northern Europe, during the month of June, he never sets, but remains all night, if night it can be called, above the horizon; and, as Berzelius well remarks, "Under the influence of this midnight sun of *the North*, the life of plants runs through the same cycle of change in

Influence of the position of the sun and length of the day.

six weeks which it takes four or five months to accomplish in beautiful Italy."

Definite quantity of heat required by plants.

Attempts have been made to establish the doctrine that every plant requires, from the time of its germination to the close of its organic activity, a definite amount of heat. The following example, in the case of barley, is furnished by Schleiden. "In Egypt, on the banks of the Nile, barley is sown at the end of November, and harvested at the end of February; the period of vegetation, therefore, amounts to about 90 days, and the mean temperature of this season is 69° 48′. In Tuqueres, near to Cumbal, under the equator, the time of sowing in the mountains for barley is about the 1st of June, the time of harvest the middle of November; the mean temperature of this vegetating season of 168 days is 50° 12′. At Santa Fé de Bogotá they number 122 days between seed-time and harvest, with a mean temperature of 57° 24′. If, now, the number of days is multiplied by the figures of the mean temperature, we obtain 6282 for Egypt, $8433\frac{36}{60}$ for Tuqueres, for Santa Fé $6489\frac{48}{60}$; therefore as nearly the same number as the uncertainty in the estimate of the days, the accurate mean temperature, and the want of knowledge whether or not the same kind of barley is cultivated in all the places, will allow us to expect. Similar results are obtained for wheat, maize, the potato, and other cultivated plants. We may express these results thus: Every cultivated plant requires a certain quantity of heat for its development, but it is the same thing whether this heat is distributed over a shorter or longer space of time, so that certain limits are not exceeded; for where the mean temperature sinks below 36° 24′, or where it rises above 71° 36′, barley will no longer ripen. Consequently, to define accurately the conditions of temperature which a plant requires to maintain it in a flourishing condition, we must state within what limits its period of vegetation may vary, and what quantity of heat it requires. This most remarkable circumstance was first observed by Boussingault, but, unfortunately, we as yet possess not nearly sufficiently accurate accounts of the conditions of culture in the various regions of the earth to enable us to follow out this ingenious view in all its details."

The effect of the intensity and quantity of heat considered.

Respecting the calculations offered in the preceding paragraph, the remark may be made that they contain an element which vitiates their correctness, and that, if the proper data were resorted to, the general principle intended to be demonstrated would be far more clearly established. The degrees of the thermometer are not the data required, for that instrument indicates the intensity, but not the quantity of heat. If some form of calorimeter were substituted for it, the result would turn out very differently. As an illustration, if a mass of ice of constant surface was exposed to the warmth in

each of these various cases, the quantity of water arising from its melting should be the same at the close of the specified number of days. In this case the true element is introduced—the element of quantity, as determined by one of the ordinary calorimetric methods.

It is not, however, to be inferred from this criticism that the peculiar quality of heat which we recognize indifferently by the terms intensity, temperature, or degree, is without significance in the case of plants: the limiting maxima and minima between which a given plant can exist prove that both conditions exert an influence, though they exert it in a different way. Doubtless a plant, from the time of its germination to that of the completion of its organic life, must have a definite quantity of heat measured out to it, but its organic functions might be fatally interfered with if the temperature should rise above a limiting maximum, or sink beneath a minimum.

The definite quantity of heat in this manner demanded by each plant is probably connected with a purely mechanical effect—the necessity for the evaporation of a definite quantity of water by the leaves. The inorganic salt substances required by every plant are introduced through its roots in a state of solution in water, and, since these salts are mostly of sparing solubility, a great quantity of water is required to accomplish the object. Nevertheless, they are dissolved at a given heat-degree in an invariable proportion in the liquid, and are required by the plant in a determinate proportion as compared with its mass; so that, were there no other reason, this doubtless would be sufficient to account for the circumstance under consideration.

Disturbance arising from the generation of heat in plants.

It should also be remembered that every plant generates a certain amount of heat, which varies with its organic condition at the time. The experiments of Professor Paine present this in an interesting point of view. The following extract is from the Medical and Physiological Commentaries, vol. ii., p. 75:

Prof. Paine's experiments.

"On the 9th of April, 1839, we repaired to a forest in New Jersey, provided with very delicate thermometers, of Fahrenheit's scale, constructed for our object. The bulbs were no larger than the stem, the range of the mercury extensive, and the degrees marked upon the glass. The stems filled exactly the bore of a small spiral auger, and when the glass was introduced the air was excluded by applying a silk handkerchief around the hole. The perforations were all made on the northern side of the trees. Fifteen minutes, at least, were allowed for the subsidence of the heat that arose from the friction of the perforator, and the thermometer was generally reapplied at different intervals afterward. The perforations were made about four feet above the ground, and the diameters of the trees were ascertained at this point. When the diameter was five inches or more, the perforations were made

to the depth of two and a half inches. When the diameter was less than five inches, the thermometer was introduced as far as the centre of the tree."

Of the tables given by Professor Paine I select the following:

"Range of thermometer in the shade during the observations, which lasted six hours, from 38° to 52°: near freezing at sunrise.

"A dead upright dry tree was selected as a standard of comparison. Its diameter was twelve inches. The temperature of this tree, at the close of our observations, was 45° at the centre and in all other parts.

"Juglans squamosa,	diameter	10	inches,	48°	Buds slightly enlarging.
do. do.	"	6	"	49°	do.
Fagus sylvatica,	"	10	"	49°	Buds swelling.
Quercus tinctoria,	"	7	"	49°	No budding.
Castanea Americana,	"	12	"	50°	do.
Betula nigra,	"	4	"	51°	Flowering.
Salix Babylonica,	"	18	"	53°	Buds unfolded.
do. do.	"	18	"	53°	do.
Pinus Canadensis,	"	18	"	54°	
Platanus Occidentalis,	"	18	"	50°	No budding.
do. do.	"	6	"	54°	do.
do. do.	"	4	"	55°	do.
Juniperus Viginiana,	"	4	"	55°	
Robinia pseudacacia,	"	3	"	62°	do.
Populus lævigata,	"	4	"	62°	In bloom.
do. do.	"	4	"	64°	do.
do. do.	"	3	"	63°	do.
do. do.	"	3	"	65°	do.
do. do.	"	2	"	67°	do.
do. do.	"	1½	"	68°	do."

The heat which is thus liberated by plants stands in the stead of a certain amount of atmospheric heat, and therefore complicates the preceding considerations.

Accomplishment of variations in the species of plants.

By such facts as those which have now been presented, we may be satisfied that the well-being of plants is affected, and even their existence determined by the influence of external agents, and that, in this manner, they are capable of having changes impressed upon them even in an artificial way. If we furnish to them those materials or conditions which their circumstances require, they will grow with luxuriance, or under an opposite state of things will dwarf away; and where, for a long period of time, such conditions are imposed upon successive generations of them, a permanent change may be effected, those which have appeared as varieties assuming the more definite form and persistency of sub-species. The general impression alluded to in the last chapter, that such peculiarities are only to be extended by budding or other equivalent operations, and that those which we regard as different individuals are truly fragments or parts of the same individual, does not here properly apply. A like propagation of peculiarity is,

in a multitude of instances, accomplished by the use of seeds, and this precisely in the instance in which we should be led to expect it. Of our kitchen-garden plants, the carrot, the beet, the turnip, the cabbage, the pea, etc., we propagate the expected kind without any uncertainty by the use of seeds, never supposing that they will run back to the wild stock, or give origin to plants different to those from which they were derived. The care of man, exerted for many years upon these vegetables, has, then, impressed upon them a change very far from ephemeral in its nature, and enabled them to pass from the condition of mere varieties into that of actual sub-species.

Necessity of long periods of time for changing plants.

Acknowledging, therefore, the influence which physical agents exert on the growth and development of plants, and admitting that favoring circumstances will bring on a modification of form, especially if applied long enough, and that man himself, by his arts of culture, can, without difficulty, establish similar variations, we might be led to expect that more profound changes in external circumstances, if steadily applied through extended periods of time, would give origin to more striking results. A variation in the constitution of the air, in the brilliancy of light, in the mean temperature, moisture, or chemical constitution of the soil, if kept up for thousands of years, or permanently established, could not fail to exert a prodigious effect upon the whole vegetable world. If, for example, the brilliancy of the sun in the slow lapse of centuries should gradually decline, or the mean temperature of the surface of the earth should descend, or enormous quantities of carbonic acid be permanently removed from the air and replaced by equivalent volumes of oxygen gas; if carbonate of lime, to an extent sufficient for the formation of geological strata, were removed from the waters, in which it could no longer be held in solution because of the withdrawal of carbonic acid from the atmosphere, it must follow, as a matter of inevitable necessity, that the whole vegetable world would feel the change. Plants that at one time existed could exist no more; others, by gradually accommodating themselves to the slow revolution, would exhibit here the development of one part, there the development of another, and some, which perhaps maintain themselves with difficulty under the old state of things, would now begin to develop themselves in a more luxuriant way.

Secular changes occurring to the earth and occasioning variations in plants.

The changes here spoken of hypothetically have, however, actually occurred in the history of the earth. We can not shut our eyes to the corresponding march which vegetation has made, commencing in the earliest geological times with the stemless cryptogamia, followed by those provided with stems and leaves, the gymnospores, such as the conifers and cycadeæ, next *making* their appearance, after these, monocotyledons, and at last the

dicotyledons—a steady progression from those which we may term of a lower to those of a more elevated organization, and all this was produced by the influence of physical agents.

On so firm a footing may we regard this doctrine as now placed, that we can use it for the purpose of determining from the ascertained botanical condition of our planet at any period the physical conditions under which she then existed, and this with a precision constantly becoming greater. Among the more important facts which have been distinctly made out, a few may be cited as illustrations of the subject now treated of. For example, 1st. The existence of a tropical climate in regions of very high latitude, as is proved by the occurrence of fossil tropical plants therein; 2d. That all over the globe the temperature was once nearly uniform, nothing answering to what we now term climates existing, as is proved by the uniformity of the vegetable growths preserved as coal from the equator to near the polar circles—great arborescent cryptogamia, exceeding in size the arborescent ferns now growing in the Pacific islands under the equinoctial line. From such a botanical fact, we reason without error to the conclusion that in those times the influence of the sun, so far as the supply of heat was concerned, must have been wholly overpowered, the intrinsic temperature of the planet obliterating all climate subdivisions. 3d. That these climate subdivisions, which are now presented as existing side by side in zones upon the planet, were introduced for each latitude in an order of succession as to time; that even the frigid zone, by reason of the cooling of the earth, has passed through an ultra-tropical, a tropical, and a temperate degree of heat to reach its present state; 4th. That the extinction of the old vegetable forms was accomplished by an inability of those organisms to maintain themselves in the physical revolution that was gradually taking place. Among such may be mentioned the dying out of gigantic equisetums or horsetails twenty feet high, club mosses rivaling forest trees, calamites and stigmarias, these, as they disappeared, being replaced by cycadaceæ, and coniferæ, and tree-like liliaceæ. Even long after the deposit of the coal there flourished in England innumerable palms, which maintained themselves, with their tropical associates, into the tertiary times.

Application of these principles inversely.

Succession of climates on the earth determined from its fossil flora.

Among the physical events which geological researches disclose, there are two of surpassing importance in the history of the globe, and both of them immediately connected with the doctrine we have under discussion; these are the change impressed on the atmosphere by the withdrawal from it of those enormous masses of carbon deposited under the different forms of coal, and the localization of plants and animals in climate distribution as the sun's rays be-

Two epochs in the history of the globe.

gan to assert their influence through the lowering of the surface temperature of the globe. The first of these events was not alone limited in its effect to a disturbance of the organic functions of plants by diminishing the amount of gaseous material from which they gathered their support in the air: its influence was also felt in animal life by rendering that possible which was not possible before —the existence of the quickly-respiring and hot-blooded tribes; for it follows as a chemical necessity that, under the circumstances of the case, the removal of the carbonic acid was attended with the evolution of an equal volume of oxygen gas. As respects the influence of the sun, which gradually led to the establishment of climates, first in an order of time, and then in an order of place, this was the signal for the localization of plants and animals in definite regions. From many countries which they had thus far inhabited they were now expelled, and barriers of temperature placed around them which they could never again overpass. And as these great changes occurred, they were attended by the extinction of countless forms in both kingdoms, which were utterly unable to maintain themselves in the new circumstances around them, their places being occupied by the extension of contemporaneous forms, or by the appearance of others that were wholly new.

Change in the composition of the atmosphere.

Definite localization of plants and animals.

As an illustration of the manner in which a vegetable organism may be used in this inverse way for the determination of physical conditions, I may introduce the following quotation from Schleiden: "The gradual conversion of the universal tropical climate into the present climatal zones may be shown in another very interesting manner in quite a special instance. All ligneous trunks of coniferous trees continually increase in thickness at all parts of their circumference. In the equatorial regions, where the climate retains the same character uninterruptedly throughout the year, this thickening of the trunk proceeds without interruption and homogeneously; no mark betrays, in a smooth, transverse section of the stem, the time which was required for its formation. As we proceed toward the north, however, as the climatal conditions produce continually-increasing diversity in the particular seasons, the corresponding growth in thickness shows itself to have been furthered by the favorable season, and restrained or altogether interrupted by the unpropitious times. In a cross section of a stem are seen, the higher the latitude in which it has grown, the greater differences in the structure of the successive portions of the wood, until finally, in the latitudes where there is a severe alternation of winter and summer, so striking becomes the difference between the wood last formed in summer and that first produced in the next spring, that we may count, in the number of annular marks thus produced in a cross section, with

Example of the inverse method from Schleiden.

great certainty and accuracy, the number of years which have been occupied in the formation of the trunk. The circular lines upon the cross section, well known to every forester, are thence called annual rings. When, fortified with the knowledge of this fact, we compare with each other the trunks of the conifers which we obtain from the various epochs of formation, we find that the oldest remains exhibit no trace whatever of annual rings, but, in the course of time, they become continually more defined, so that lastly, in the most recent formations—for instance, in the upper brown coal—they appear marked just as distinctly as in the trees now living in the same localities."

Difference between abrupt and gradual impressions on plants.

In speaking of artificial changes impressed by culture upon domestic plants which have been converted from varieties into sub-species, the importance of the element of time was insisted upon. In the same manner, in the changes which have occurred during geological periods, the successive replacement of one class of vegetable forms by another, that element again obtrudes itself upon our notice. If a few years serve to establish such minor changes as the perpetuation of varieties into sub-species, what should be expected from the enduring influence of innumerable centuries? Moreover, in these artificial results there is a necessary abruptness in the application of the disturbance, which can not but exert an unfavorable influence. No time is afforded to the organism to suit itself gradually to the force exerted upon it, none for acclimating itself to the external variation. It must either yield at once or perish. But how different as respects the method of application in the case of the organic series! If it be decline of temperature that we consider, how shall we enumerate the successive centuries that must have elapsed as the descent was made from degree to degree? In these later times, as is admitted on all hands, the mean temperature of the surface could not decline the tenth part of a Fahrenheit degree in the lapse of 10,000 years. Yet the interval has transpired during which there has been a gradual descent from those high thermometric points at which the existence of organic life was barely possible, and, in truth, through a far greater range than that. It signifies nothing that this descent might have been more rapid the higher the degree; in any case, it implies a prodigious interval of time. Or, if we consider variations in the light of the sun, either because of his being a variable star, or because of the gradual clearing up and improving transparency of the atmosphere, we are brought again to the same result—long periods of time; for, though there may be among the fixed stars some whose periods of variation, as respects brilliancy, are short, included perhaps within a few days, or even hours, if we had no better evidence, history assures that our sun is not one of that quickly-varying group. Or, again, if we consider the changes which have indisputably

occurred in the chemical constitution of the air, the diminution of its ancient amount of carbonic acid, the reduction of the mean percentage of its vapor of water, the increase of its oxygen, these again are changes of a secular kind, the time required for the accomplishment of which is wholly beyond our finite comprehension. In such a gradual advance, organisms for many generations might show but little change, yet, in the end, the effect must come to be profound. Indeed, all the great natural effects we witness are accomplished in this quiet and gradual way: the traces of tempests and other catastrophes are very soon effaced, no matter how violent the original commotion may have been; but warmth, and light, and moisture—causes which act so gently that we might overlook them—are the agents which control the universal aspect of things. In this, as in other respects, the strong are always the silent; and in the slow lapse of many centuries, by the gradual operation of universal forces thus gently applied, organic forms had an opportunity of accommodating or acclimating themselves to the new state, or, if they failed to do so through some want of correspondence in their structure, they gradually passed away and became extinct. It is no argument against the transmutation of species, or even of genera, that we have never witnessed such an event. We can never witness the necessary combination of circumstances which should bring it about, above all, as regards the needful lapse of time, the slow yielding and accommodation which such a change implies. In this, as in those great modifications that have occurred in the stratification of the globe, the like of which has never been seen in the periods of human record, our want of familiarity with them is a matter of very little moment. The remark of an eminent geologist applies with equal force in both cases: "Changes that are rare in time become frequent in eternity."

Secular physical changes attended by productions and extinctions.

But it may be said that if by external influences the successive species and genera in this manner arose, we ought to find, even between those which are most closely allied, many intermediate forms; for, since the active causes were gradual in their operation, one organism should pass into another by slow degrees—so insensibly, indeed, that it would perhaps be impossible to indicate the point at which the proper transition was made. Such an expectation is, however, founded upon a total misconception of the character of these progresses, for a force applied for thousands of years may show no effect, but at last may manifest itself by an instant crisis. Multitudes of illustrations might be furnished of this principle; for instance, the motion of a comet may be toward the sun in a path which is almost a straight line for scores of centuries, but on a sudden it assumes a curvilinear course, and accomplishes its perihelion passage in perhaps a few

Gradual change in causes may produce effects by abrupt crises.

hours, and then, receding from that luminary, takes a course not sensibly differing from a straight line, and occupying perhaps centuries in its accomplishment. The variations of direction and of velocity are, however, the necessary results of the conditions under which its movement is taking place, and may be truly said to have been originally included therein.

This instantaneous or critical assumption of a new phase may also be illustrated by the functions of organic beings. Thus the fœtal mammal, though provided with lungs, a mechanism in all respects ready for aerial respiration, does not pass by graduated steps from placental, which is truly aquatic breathing, but the change takes place on a sudden at the moment of birth. These and other such instances may therefore satisfy us that what an imperfect induction would lead us to look upon as a departure from the existing rule, or as a breach of the law, may, in reality, be nothing more than the immediate or legitimate consequence of it. They may teach us that, in the natural progress of things, variations do not necessarily always take place in so gradual a manner as to be undistinguishable from stage to stage, but sometimes instantaneously, and, as it were, by a crisis.

Illustration from the life of man.

Again, this variation by crises may be illustrated by many familiar mechanical contrivances. The case of the common seconds striking clock may furnish an example. Let us trace the successive conclusions to which an ingenious man might have come at the first introduction of this instrument, his investigation of it being supposed to exclude an inspection of its parts. After listening for a length of time to the beats of its pendulum, he would observe that these succeeded at precisely regular intervals, and after extending his examination through two or three thousand of such occurrences, he would doubtless feel justified in coming to the conclusion that the construction was of such a nature that the passage of successive small intervals of time was indicated by the occurrence of a brief, dull sound. His first conclusion, therefore, would be, that the instrument would go on doing this continuously.

Mechanical illustrations.

At the close of 3600 such observations, when the truth of his induction appeared to have become irresistible, his attention would be arrested, and his faith in the correctness and completeness of the extensive inductive conclusion he had just drawn would be shaken by hearing one loud stroke upon a bell. Now, probably, he would suspect that the structure of the instrument was such that it indicated the lapse of each 3600 minor beats by one louder stroke. This would be his second and more improved induction.

Setting himself to verify the truth of this hypothesis, he would watch the instrument through 3600 beats more, confidently expecting that, at

the conclusion thereof, the hypothesis to which he had thus hastened would be confirmed. True to the time, the bell would again strike, but, instead of striking only once, it would strike twice. Admonished of the hastiness of his hypothesis, our philosopher might now be induced to pause before he generalized again, and, after watching through 3600 more beats, the clock would strike thrice.

Now, surely, he would feel absolutely certain of having reached the true interpretation of the action of the machine at last. His third and corrected conclusion would be that each group of 3600 beats was registered by the bell, the number of strokes upon which indicated the number of such groups, and that this it would do continuously.

Patiently listening through many thousand beats, he would find that every thing confirmed his new and improved induction. He would hear, in their regular succession, ten, eleven, and twelve strokes made by the clock. Of course, his expectation would now be confirmed that at the next time the clock struck it would be thirteen. How great would be his surprise to find it was only one!

Perseveringly continuing his examination, he would reach, at last, the true law regulating the indications of the machine, and would find that the partial conclusions to which he had successively arrived, and which he had thought, at the time, to be substantiated by a superfluity of facts, were in themselves incomplete, and in that respect erroneous; but he would also observe that whatever truth there was in them was embraced in the final induction that the machine was not as simple as he had at first supposed, and that the critical variations which in succession had surprised him were all embraced in the original plan of its construction. Our imaginary philosopher has passed through a mental exercise precisely like that which is befalling modern comparative physiologists. From his labors, disappointments, and eventual success, they may gather encouragement. The clock of the universe does not forever go on vibrating monotonously. A thousand years upon it are only as the beat of a pendulum; but it, too, has its periods of critical variation—variations that were included in its original device.

Application of the preceding illustration.

The point which I wish to impress by these illustrations is, that there is a definite career which an organism must follow, according to its exposure to existing physical conditions, and that, though this career may seem to be continuous, it by no means follows that it shall not exhibit an instantaneous and critical change, and that, on a sudden, the organism may assume a specifically new aspect; and though, in what has thus far been said, reference has been had chiefly to plants, these observations all apply, in like manner, to animals. I do not propose, however, to enter on that branch of the inquiry now, but, as an illustration of the influence of

Influence of physical agents on the form of man.

physical agents, even on the highest—man himself—shall offer the following example:

M. D'Orbigny, in his description of the Inca Indians of South America, remarks, "It has always been observed that the trunk is longer in proportion than among other Americans, and that, for the same reason, the extremities are, on the contrary, shorter. We endeavored, at the same time, to explain this fact by the greater development of the chest. It would appear that any part of the body may take a greater extension from any adequate cause, while other parts follow the ordinary course. An evident proof of this fact may be found in the phenomena of imperfect conformation, in which a certain part of the body, in consequence of deformity, does not assume, in external appearance, its complete natural development, as we see in the trunk of a dwarf, while this defect does not prevent the extremities from acquiring those proportions that they would have had if the trunk had received its full growth. This accounts for the want of symmetry in the persons of dwarfs, and for that length of the upper and lower limbs so much out of proportion to the body. If we admit this fact, difficult to contest, why, in the case in question, may we not as well admit that the chest, from a cause which we shall explain, having acquired a more than ordinary extension, might naturally lengthen the trunk without causing the extremities to lose their normal proportion, which would make it appear, as indeed it would be, longer than among other men where no accident can have altered the form common to the race?

Case of the Inca Indians.

"Let us return to the causes which occasion in the Incas the great volume of chest which has been observed in them. Many considerations have led us to attribute it to the influence of the elevated regions in which they live, and to the modifications occasioned by the extreme expansion of the air. The plateaux which they inhabit are always comprised between the limits of 7500 to 15,000 feet above the level of the sea. There the air is so rarefied that a much greater quantity must be inhaled at each inspiration than at the level of the ocean. The lungs require, in consequence of their great necessary volume, and of their greater dilatation in breathing, a cavity larger than in the lower regions. This cavity receives from infancy and during the time of its growth a great development entirely independent of that of the other parts. We were desirous of determining whether, as we might suppose *à priori*, the lungs, in consequence of their great size, were not subject to extraordinary modifications. Inhabiting the city of La Paz, upward of 11,000 feet above the level of the ocean, and being informed that in the hospital there were constantly Indians from the populous plateaux still more elevated, we had recourse to the kindness of our countryman, M. Burnier, physician to the hospital, and he permitted us to make a post mortem

examination of some of these Indians from the highest regions. In these we have, as we expected, found the lungs of an extraordinary dimension, which the external form of the chest clearly indicated. We remarked that the cells were much larger and more in number than in those of the lungs we had dissected in France; a condition very necessary to increase the surface in contact with the ambient fluid. To conclude, we have discovered, 1st. That the cells were more dilated; 2d. That their dilatation increases considerably the volume of the lungs; 3d. That, consequently, they must have to contain them a larger cavity; 4th. That, therefore, the chest has a much larger capacity than in the normal state; 5th. That this great development of the chest elongates the trunk beyond its natural proportions, and places it almost out of harmony with the length of the extremities, this remaining the same as if the chest had preserved its natural dimensions."

Argument from the extinction of forms.

With respect to the doctrine of the influence of physical agents on organization generally, we admit without hesitation that the *extinction* of forms has been accomplished through outward causes, decline of heat, etc. These extinctions are intimately connected with the appearance of new organisms, and, indeed, are to be regarded as being, with them, essential parts of a common plan. It would not appear agreeable to the mode in which the scheme of Nature is carried out to invoke one class of influences for the removal of the vanishing forms, and a totally different one for the introduction of the new-comers. There seems to be a better harmony in the supposition that all these things are managed upon similar principles, and that, since it is the failure of congenial conditions which closes the term of life of a race, it was the suitability of those conditions, or their conspiring together, which gave it origin.

Influence of decline of temperature.

The influence of decline of temperature appears when we examine particular individuals or particular species either of plants or of animals. Thus the Virginia cherry attains the height of 100 feet in the Southern States, and is dwarfed to a shrub of not more than five feet at the great Slave Lake; the nasturtium, which is a woody shrub in warm climates, becomes a succulent annual in cold. Or, if we examine some special tribe of life, as Milne Edwards has done in the case of crustaceans, the higher the temperature, the greater the liability to variations of species, the more numerous also the differences of form, and the attainment of a greater individual size. That these variations are the actual consequences of the physical conditions, and not merely collateral results, is shown by supplying the condition that is wanting. We can imitate the natural result, in an artificial way, in hot-houses; the plants of the warmest climate may be grown, and the effects of summer imitated at any season of the year. What better proof could

we have of the control of the agent heat over development, than the well-ascertained fact that the time of emersion of larvæ depends upon the temperature? The silk-grower, by placing the eggs of the insect in an ice-house, retards them as long as he pleases. The amputated limbs of the water-newt can only be reproduced at a temperature from 58° to 75°. The tadpole, kept in the dark, does not pass on to development as a frog. In decaying organic solutions, animalcules do not appear if light be excluded.

Changes of organization depend on invariable laws.

Upon the whole, therefore, we conclude that organisms of every kind, so far from presenting any resistance to change, are impressed without any difficulty by every exterior condition; and since existing natural circumstances have been maintained for a long time without any apparent change, their sameness produces a sameness in the order and manner of development. But it should be borne in mind that this idea of sameness can be entertained only on an imperfect view of the state of Nature, for there is scarce one of those conditions, to the sameness of which we have been referring, which has not, in reality, undergone slow secular variations; and with those changes there have been changes in the manner of development.

Successive metamorphosis a consequence of invariable law.

In truth, as I have on a former page observed, the only things which are absolutely unchangeable are the laws of Nature, such, for instance, as that of gravitation; every thing else is to be looked upon as an effect, or as a changeable phenomenon arising from the operation of those laws. So, therefore, though, in this chapter, the terms physical influences and natural conditions have been repeatedly used, yet a higher and more philosophical view of the case brings us inevitably at last to the idea of law; and therefore I accept the interpretation of all these facts, which has of late years been impressing itself more and more strongly and clearly on the minds of physiologists, that the development of every organism, from a primordial cell to its final condition, however elevated that condition may be, is the inevitable consequence of the operation of a universal, invariable, and eternal law.

All animals, no matter what position they occupy in the scale of nature, unquestionably arise in the first instance from a cell, which, possessing the power of giving birth to other cells, a congeries at last arises, the size and form of which is determined wholly by external circumstances. In all cases, the material from which these cells are formed is obtained from without, and, whatever the eventual shape of the structure may be, the first cell is in all instances alike. There is no perceptible difference between the primordial cell which is to produce the lowest plant and that which is to evolve itself into the most elaborate animal. The mode of growth, and the arrangement of the new cells as they come into existence, determining not only the form, but also the functions of the new

being, depend on the particular physical conditions under which the growth is taking place. The germ which is to produce a lichen obtains from materials around it the substances it wants as best it may; but the germ which is to end in the development of man is brought in succession under the influence of many distinct states. As a consequence of this, it gives rise in succession to a series of animated forms, which, assuming by degrees a higher complexity, end at last in the perfect human being. At one time it was believed that these metamorphoses, as they are termed, are limited to insects and frogs: the insect, which at first appears under the form of a caterpillar as it comes from the egg, and, passing through the pupa state, at last takes its true position as a winged being; the frog, which, appearing at first from the ovum as a true fish, whose respiration is carried forward by gills, and whose life is limited to the water, at last assumes a new constitution and a new organization, breathes by lungs, and becomes an amphibious reptile. But it is now known that these, so far from being exceptions, are only instances of a general rule, which is, that all organized beings shall begin existence at the bottom of the scale, and, taking on one type of life after another, in more or less rapid succession, end, finally, in assuming a size and form analogous to those of the parent which gave them birth.

There is a general resemblance between the life of an individual and the life of a species. Each has its time of birth, its time of maturity, its time of decline; each also has its embryonic states. The fossil forms of the early geological ages are in many cases the embryos of existing animals. Upon each all natural agents have exerted their effects, pushing forward or retarding development; and this applies not only to animals, but also to plants: it is in accordance with the principles we are setting forth that over the whole domain of life natural forces exert their sway. Change the conditions under which growth is taking place, and you at once change resulting form and function. It is in this manner that, on a small scale, the horticulturist works in furnishing us what are called improved varieties of flowers and fruits. It is in this manner that animals, known to have been indisputably of the same original kind, assume such different forms and characters in various climates. It is true, we can not expect in an abrupt manner to bring about such striking modifications in a solitary individual, for the life of an individual is readily destroyed, but not so the life of a race; and Nature, carrying on her operations in the slow lapse of centuries, and dealing with races rather than individuals, forces them up to any point of development she may desire, but still the impress of the laws under which they have been brought to that condition is upon them, and each betrays, in the embryonic and fœtal forms, a manifestation of the metamorphoses through which his race has run.

Our attention might here be directed to that interesting class of phenomena known to comparative anatomists under the title of rudimentary organs—that is to say, organs which exist in an apparently undeveloped and useless condition, such, for instance, as the mammæ of the male mammalian, or the subcutaneous feet of certain snakes—for these are facts intimately connected with the subject before us. It looks as if Nature stopped short in her attempt at reaching perfection, but it proves to us the constancy of the plans on which she works. In the case of the whale, which, though apparently belonging to the fishes, is a warm-blooded mammal and suckles its young, the general type of its class is observed even down to minute particulars; it is the attribute of those belonging to it that they shall have seven cervical vertebræ, and this is equally the case with the camelopard, with its long, graceful neck, and the mole, which seems to have no neck at all. In the whale, which conforms to that general rule, the teeth are, moreover, found in the jaw, in the earlier period of life, uncut, precisely as we find them at birth in the human infant. In this last instance we think we see a wise provision and foresight of nature, which does not give to man these masticating organs before the time they are wanted; but what are we to make of the former case? Man is not always a true interpreter of the works of God. Shut up, as they are, in the interior of the bony mass of the jaw, never to be developed and never to be used, does not that look to a careless observer something like a work of supererogation? Or, in the case of such snakes as the anguis, typhlops, and amphisbæna, why is it that Nature has placed under the skin the bony representatives of the extremities: the mode of progression of those animals is by the use of the ribs, and organs such as feet are never wanted.

Rudimentary organs and their interpretation.

We may also turn to the other department of physiology, the vegetable world, and what do we there see? Rudimentary organs and excess of development are every where presented. An attentive examination of any flower proves that we may with truth regard it as a transformed branch, the law of development being such that that which might have passed forward to the condition of a branch has turned to the condition of a flower; or, in still minuter particulars, we witness the same principle: that which might have evolved into a leaf turns indifferently, as circumstances may direct, into a sepal, a petal, or a stamen.

But is it possible that there is all this confusion and want of precision in the works of Nature? Not so. If we consider rightly, we shall come to the conclusion that Nature never works contingently, nor resorts to a sudden contrivance to meet an exigency. All her operations are carried forward under far-reaching and universal laws. These rudimentary and perhaps useless organs come into existence through a general plan, of which they are

Appearance of rudimentary organs the consequence of law.

witnesses to us, if they subserve no other duty. They tell the same great fact which is so loudly proclaimed by all the phenomena of the restoration of parts and renovation of tissues, that the grouping of organized matter into definite and special forms is not a wanton or chance effect, but is the direct and inevitable consequence of invariable physical laws.

Expedients are for the vacillating and weak, law is for the strong. It takes from the merit of any human contrivance if the engineer has to be constantly tampering with it to keep it going; we admire the machine that continues its movements without variation after it has left its maker's hand. I think we can have no nobler conception of the great Author of the wonderful forms around us than to regard them all, the vegetable and animal, the living and lifeless, the earth, and the stars, and the numberless worlds that are beyond our vision, as the offspring of one primitive idea, and the consequences of one primordial law.

CHAPTER III.

OF THE ORGANIC CELL: ITS DEVELOPMENT, REPRODUCTION, AND DIFFERENTIATION OF STRUCTURE AND FUNCTION.

Simple and Nucleated Cells.—The Simple Cell: its Parts and Functions.—The Nucleated Cell: its Parts and Functions.—Activity of the Nucleus.—Other Forms of Cells.—Cells arise by Self-origination and Reproduction.—Reproduction by Subdivision and Endogenously.
The Animal Cell.—Forms of Cellular Tissue.—Forms of Vascular Tissue.—Spiral Vessels, Ducts, etc.
Differentiation of Cells.—Acquisition of new Functions.—Differentiation of the Animal Cell.—Depends on Physical Causes.—Influence of Heat and Air.—Epoch of Differentiation.

Simple and nucleated cells.

THE organic cell, which is the starting-point of every organism, vegetable or animal, consists of a vesicle or shell, with included contents. If the vesicle be of uniform thickness all over, the cell is a simple one; but if there be upon some portion of it a thickened granular spot, the cell is said to be nucleated.

The simple vegetable cell: its wall, utricle, and endochrome.

The vesicle of the SIMPLE VEGETABLE CELL, more closely examined, is found to be composed of different laminæ or strata. The innermost, designated the primordial utricle, consists of an azotized substance, a member of the protein group. On the exterior of this pellicle, and, as it were, arising from its surface, lies the cell wall, which serves to give protection to the parts within. The cell wall is not a mere extension by thickening of the primordial utricle, as is proved by its chemical constitution; for, though it may vary in physical condition from a mere glairy mucus to a firm woody

texture, it uniformly consists of a non-nitrogenized body, gummy, amylaceous, or ligneous. Indeed, though the vegetable cell is usually said to have two concentric investitures, the nitrogenized primordial utricle and the non-nitrogenized wall, it is more exact to describe the latter as consisting of several pellicles, which have been generated in succession from the outside surface of the utricle, and these differ from one another in their physical qualities, according as they are nearer to the surface of the utricle or nearer to the general exterior, recalling, in this respect, the analogous condition of the cuticle under circumstances that are somewhat parallel.

Within the primordial utricle, the cell contents present themselves of a different nature and different form, according as the species of the cell may be. In different cases they are colored of various tints, and are of various consistency, more solid or more liquid. To the cell-contents the convenient designation of endochrome is given. This interior content is not to be understood as having a homogenous constitution, since sometimes even its colored portions are separated out and arranged in dots or spiral lines, which are very distinct from the remaining uncolored material.

The active portion of such a cell consists of the utricle and endochrome conjointly, the cell wall only discharging a mechanical office. In the simple cell, all parts of the utricle appear to be endowed with equal power for carrying on the functions of the organism.

Nucleated cell: activity of its nucleus.

But in those cells which possess a nucleus, the energy is no longer diffused with uniformity, the nucleus concentrating much of the power in itself, and serving as a centre of activity. Its nitrogenized constitution indicates that it is in relation with the primordial utricle, and not with the cell wall; a conclusion which is corroborated by its physiological activity, as also by the fact that in those nucleated cells which exhibit currents, the nucleus appears to be the starting-point from which they diverge in various directions.

Subordinate forms of cells.

There are subordinate species of cells, as the spiral and the dotted. These exhibit points of re-enforcement or thickening, such as the appearance of a thread wound spirally, or in dots here and there on the interior of the wall. There would seem to be a tendency during the development of a cell for these parts to assume a spiral arrangement. Even the endochrome shows this peculiarity, the green material being often arranged in a spiral course on the interior of the cell.

Thus constituted, each cell runs through a definite cycle or career, having its moment of birth, its period of maturity, its time of death. During its mature life it discharges with activity the special function to which it is devoted, but in so doing becomes eventually worn out and old. The period of activity of cells of different species is very different, some passing away quickly, and others having a longer duration.

The commencement of cells is either, 1st, by self-origination, or, 2d, by reproduction.

Origin of cells by self-origination.

1st. Cells arise in an obscure manner from homogeneous particles floating in a protoplasma, which, taking on development, have a vesicle thrown over them, and, being of a spherical shape, present the aspect of a cell wall and cavity. The granular content by degrees increases as the young cell grows in all its dimensions. From that granular content new cells may arise.

Though this process is spoken of as one of self-origination, it is quite probable that the spherical and homogeneous particles floating in the protoplasma, and which were the points of origin of the cells that have arisen, were themselves nothing more than germs which had been prepared by an antecedent generation of cells. This is the opinion commonly entertained of their nature, though its truth has never yet been demonstrated by actual observation. It is adopted because of its probability, for we usually observe that every new organism is the descendant of an older one; yet it should not be forgotten that there must have been a time when the first organic cell arose from inorganic material, and it is not unphilosophical to suppose that what must have occurred once may occur again.

Origin of cells by reproduction.

2d. Cells are reproduced from antecedent ones of the same kind by subdivision, by budding, by endogenous generation.

Reproduction by subdivision.

The reproduction of cells by subdivision is strikingly illustrated by the Hæmatococcus binalis. The manner of the process seems to be as follows. The endochrome of the original spherical cell, *a*, *Fig.* 230, begins to undergo bi-partition as at *b*, and as the dividing portions recede from one another the primordial utricle bends round them. Next a layer of permanent cell wall, of a mucous character on its exterior, is produced, which accompanies the inflection of the primordial utricle as at *c*, and, after a while, the bi-partition is complete, and the separated portions constitute distinct individual cells. The subdivision may be repeated as at *d*. The seat of the primary action is said to be in the endochrome; but of this there may be reasonable doubt, since generally the primordial utricle is the place of energy of the cell; and where nucleated cells undergo multiplication by this process of fissure, the nucleus divides along with the endochrome, so that both the resulting portions possess a part of it. But if the utricle, with its nucleus, was inert during this operation, it would seem that the vesicle should tear any where

Fig. 230.

Reproduction of Hæmatococcus binalis.

rather than through that thickened and stronger place. The phenomena are equally well accounted for by imputing the first action to the utricle itself, which, exerting a constrictive pressure upon the endochrome in the direction of one of the great circles of the cell, divides it in the manner that we see.

This process of multiplication is exhibited in *Fig.* 231, in Conferva

Fig. 231.

Cell reproduction in Conferva glomerata.

glomerata, which consists of a system of cells arranged in a filament. At A two states are shown, complete partition at *b*, and incomplete at *a*; at B, C, D, the successive steps of partition, *a* being the primordial utricle, *b* the endochrome, *c* cell membrane, *d* mucous investment. At E the primordial utricles are separated, and the cell membrane intervenes. At F the membrane is completed so as to exhibit laminæ.

The cells which have thus arisen by subdivision soon grow to the size of the one from which they were derived, and are ready for subdivision in their turn. Indeed, it often happens that traces of incipient subdivision may be detected long before the cell has reached its mature dimensions.

The reproduction of cells by budding may be illustrated by the vesicles of the yeast-plant; and though, in those cases in which the budding cell possesses a nucleus, the nucleus is not necessarily involved, yet the conclusion indicated in the preceding paragraph is greatly strengthened, for we must clearly attribute the result which now takes place to an increased nutrition of the primordial utricle upon a restricted portion of its surface, and not to a distention arising from a pressure of the endochrome within. So closely does this resemble the preceding mode of reproduction, that they are commonly said to be really of the same kind, or, rather, to offer no other distinction than this, that in the former the

cell divides into portions which are sensibly equal, in this into unequal parts.

Endogenous generation of cells.

Cells are said to arise from endogenous generation when they make their first appearance in the cavity of a former cell, of which the endochrome exhibits a disposition to divide into many small portions, at first doubtfully, then more distinctly, and each one of these portions obtaining a covering investiture or primordial utricle for itself. The process continues until the young brood of cells has reached a certain degree of perfection, when they escape from their confinement, either by the fissuring or deliquescence of the old cell wall. The young cells may now lead an independent life and grow rapidly. In this manner zoospores arise, which are young cells having for a time a power of locomotion, from cilia which have been developed from their walls, or for other reasons.

The reproduction of cells by endogenous generation is commonly attributed to an action arising in the endochrome which brings on its subdivision into portions. From the fact that these portions are eventually found clothed with a primordial utricle, we might be led to suspect that the original seat of the action is in this, as in the preceding cases, that portion of the original cell which, undergoing projection internally, divides the endochrome and incloses the portions in its meshes. Such membranous projections may be difficult of detection in the first instance, because of their extreme tenuity; nor is the fact that the zoospores move freely in the cavity of the mother cell just before their escape at all in contradiction to this.

Peculiarity of the animal cell.

THE ANIMAL CELL presents a structural arrangement differing from the vegetable in this, that it does not possess a proper cell wall, but consists of a primordial utricle and interior content alone. Its manner of reproduction is of three kinds: 1st. From germs; 2d. By fissure; 3d. Endogenously. Where animal cells originate from germs, these seem to be granules of a substance analogous to fibrin, which are floating in the formative liquid. In duplication by subdivision, the import of the nucleus is shown by the fact that the action begins at it. It may be said of animal cells that the nucleus maintains a more conspicuous relation than it does in the case of vegetable ones. Reproduction in the endogenous manner is carried forward in the case of these cells in the manner described in a preceding paragraph.

OF THE CONSTRUCTION OF CELLULAR AND VASCULAR TISSUES.

Cellular tissue, its various forms.

By their development and juxtaposition with one another, cells give rise to continuous fabrics of various kinds, or cellular tissue. If the development of new cells occurs in a space where there is freedom from pressure, the cells maintain their original

spherical form, as seen in the photograph, *Fig.* 232. But should the development occur in a confined space, or under circumstances of pressure, the intercellular spaces which necessarily exist in the former case by reason of the spherical shape, are now encroached upon, and the cells assume various angular forms, such as parallelopipedons, rhombic dodecahedrons, &c. Of the former we have an example in the photograph, *Fig.* 233, which represents a section of muriform cellular tissue. In other cases, with a view of giving resistance to pressure, the interior of each of the cells is fortified by a fibre, and thus arises the tissue of which we have an example in the photograph, *Fig.* 234. Two or more fibres may, in this manner, be employed, and when such is the case, it is observed that they do not cross one another, the one winding from right to left, the other from left to right, but they are laid parallel to each other, and form a compound strand. In other cases the constituent cells of the tissue assume much more complicated forms, as, for instance, in the stellate variety. These more complicated forms prove that it is not altogether through the influence of a force of compression that cells assume modified shapes, but that on many occasions the disposition of their primordial utricle to branch in various directions, of which mention has been made in a preceding paragraph, is the true cause of the variations in question.

Fig. 232.

Simple cellular tissue, magnified 50 diameters.

Fig. 233.

Muriform cellular tissue, magnified 50 diameters.

Fig. 234.

Fibro-cellular tissue, magnified 50 diameters.

This disposition to grow spontaneously in one direction rather than in another is the cause of the production of the different kinds of vascular tissue. A cell undergoing extreme elongation in one direction, either by

Vascular tissue and its modifications.

reason of this quality of its primordial utricle, or through unequal nutrition, or other cause, gives origin to a tube. And if, of several cells thus elongated, and placed end to end on each other, the terminal portions should be obliterated either by rupture or absorption, a vessel permeable throughout is the result. In this manner vascular tissue arises. These vessels still exhibit the structural peculiarity of the cells from which they have originated in this, that they may be fortified in their interior with fibres wound in a spiral, and so constituting a spiral vessel; or wound in rings, and forming annular ducts. In like manner, through similar modifications, the varieties known as reticulated and dotted ducts arise. In these fibro-vascular tissues it frequently happens that the fortifying thread is double or even quadruple. Of spiral vessels derived from a cactus we have an example in the photograph, *Fig.* 235, and in those from the banana in that of *Fig.* 236.

Fig. 235.

Spiral vessels of cactus, magnified 50 diameters.

Fig. 236.

Spiral vessels of banana, magnified 50 diameters.

Spiral vessels, dotted ducts. Vessels of conifers.

The spiral vessels of plants contain air. Other tubes are for the conveyance of liquid; the laticiferous vessels, for example, which are branching tubes for transmitting the latex of plants. Again, in other cases, the interior of the vessel is more or less completely filled up by a gradual deposit of solid material, it being in this manner that proper woody fibre is formed from long, spindle-shaped cells. Vascular tissue in coniferous plants presents a peculiar dotted aspect from disc-like forms, exhibiting a pair of concentric circles, which are set at regular intervals upon it, as shown in the photograph, *Fig.* 237,

Fig. 237.

Woody fibre of pine, magnified 50 diameters.

which is dotted woody fibre from pine. The circular discs or glands run in single rows except in one place, where a double row is seen. Among true living pines more than two rows are not met with. In the Araucaria the rows are sometimes triple or even quadruple.

Animal vascular tissue arises in the same manner as vegetable, by the conjunction of elongated cells and the obliteration of their terminations. The physiological purposes these vessels subserve are, as in the other instance, the conveyance of gases or liquids. But fibres may form in animal fabrics without the previous intermedium of cells, either directly from fibrin, the parts of which possess the quality of agglutinating into threads, or from the coalescence under like circumstances of substances allied to gelatine, which yield the varieties of fibrous tissue known respectively as the yellow and the white, the former being composed of branching filaments, as seen in *Fig.* 238. It is unacted upon by warm acetic acid, and, from its extraordinary elas-

Yellow and white fibrous tissue.

Fig. 238.

Yellow fibrous tissue, magnified 300 diameters.

Fig. 239.

White fibrous tissue, magnified 300 diameters.

ticity, is used wherever that quality is required. The latter, which is represented in *Fig.* 239, shows strands of a wavy appearance: it is inelastic, softens under the action of acetic acid, being thereby distinguished from the preceding, and is employed on account of its tenacity wherever resistance to extension is required, as, for example, in the ligaments of the joints. The solid animal fibres are therefore employed where physical qualities are necessary, the hollow tubes for organic processes. By some physiologists it is believed that both yellow and white fibrous tissue arise from cells.

Fig. 240.

Areolar tissue, magnified 25 diameters.

Areolar or connective tissue, *Fig.* 240,

is composed of the two preceding elements, the yellow and white fibrous, interwoven with each other so as to constitute a porous structure, with a multitude of intercommunicating spaces. It is to be understood that these interstices are wholly distinct from cells; hence the inapplicability of the term cellular, sometimes employed for this tissue. Areolar tissue is employed for uniting the various animal parts. Its interspaces are filled with a fluid, which, when in excess, is spoken of as dropsical effusion. Air, artificially or accidentally introduced at any point into it, may pass to every part, as is illustrated in cases of emphysema. The specimen from which the figure is taken was in this manner inflated.

Differentiation of cells.

By the differentiation of cells is meant the assumption of a variation in their structure from which follows, as a consequence, the capacity of discharging new functions. When the red snow-alga multiplies, as previously described, each of the young cells resembles that from which it was derived in structure, and discharges a similar office. In such a case there is development, but not differentiation. When, on the contrary, a lichen grows on a rock, though the original tendency in development may have been for the production of cells from the first germ absolutely similar in all directions, yet the circumstances of growth are such that very soon the physical conditions under which the cells of different parts of the growing mass are generated become different. Those which are next to the rock are screened by the superincumbent ones from the sunlight and the air; they are therefore developed in a comparative obscurity, and in the presence of moisture holding in solution inorganic salts. Under such circumstances, it is to be expected that a modification will ensue in their construction, and that they will be different from those which are developing on the exterior in contact with the dry air; and, since a change of structure invariably implies a change of function, we might expect, as in reality is the case, that the outer cells are for the obtaining of carbon from the air, being acted upon by the sunlight, and the under cells for procuring moisture and such saline substances as may be wanted from the rock surface below. In such a case as this there is a differentiation both of structure and of function.

Acquisition of new functions.

Differentiation in a regular sequence appears to be determined by law.

Structural differentiation is to be received as the cause of functional differentiation, which is its consequence. The former, in every instance, arises from the changed circumstances under which cells are being generated, and if this change of circumstances follows a regular order or sequence, the differentiation will assume the appearance of being guided by a fixed law. Many physiologists, who have not been disposed to accord to physical agents a due influence in this respect, have therefore imputed to the developing *cell* a power or property of spontaneously pursuing a determinate career.

It is clear that the facts are capable of interpretation either upon the doctrine that external conditions guide or compel the cell in its developmental career, or that it, by reason of an innate power, spontaneously pursues a determinate course in spite of them; determinate, because that power is acting under a law. The mixed doctrine, which imputes the career of development in part to the innate power of the cell, and in part to the influence of external conditions, it is needless for us here to consider.

No doubt can be entertained of the fact that a cell or congeries of cells will differentiate when submitted to new physical conditions while in the act of development. Thus certain lichens pass into forms analogous to algæ if the normal conditions of their production be reversed—if, instead of developing in places that are dry and brightly illuminated, they are supplied with moisture, and made to grow in obscurity; and, in like manner, some of the fungi will simulate algæ if they are compelled to vegetate in water.

The separation of the organ for the reception of water and that for the reception of carbon, which is first shadowed forth in the under and outer surface of the lichens, is manifested in perfection by highly-developed plants, in which the root discharges the former, and the leaves the latter duty, and these are separated widely apart from each other by the ascending axis or stem.

Differentiation of the animal cell.

The remarks here made respecting plants might be repeated as regards animals, which, during their development, exhibit the principle of differentiation even in a more striking way. Thus, in the protozoa, as in the protophyta, cells undergo duplication, and, by development in new positions, or under changed circumstances, exhibit differentiation. The trivial circumstances under which new functions are assumed are well shown in Trembley's experiments with the hydra. This polype, which is nothing more than a gastric sac furnished with prehensile tentacles, respires on its outer surface and digests on its inner; but so closely are these functions blended together that, if the animal be turned inside out, the surface that did respire will now digest, and that which did digest will now respire. Indeed, we may in an ideal manner conceive of the production of the more elementary animal forms as arising from a simple sac or bag, which, furnishing a starting-point, exhibits its first acquirement of localization of function by the doubling of one half into the other, thereby giving rise to a cup or pocket shaped form, so that respiration and digestion, which were confusedly and conjointly carried forward upon the same surface, are now parted from each other, the outside of the cup being devoted to the one, and the inside to the other. Increased endowments are obtained by crimping or dividing the edge of the cup, prehensile organs of less or greater length

Experiments with the hydra.

Ideal differentiation of animals.

and power thereby arising; and this, in reality, is the structure of the hydra just alluded to. Another advance is made by the preparation of new and complicated structures, fashioned out in the substance between the inner and the outer wall, and in this manner arise the various mechanisms for respiration and reproduction. Such a state of things is presented by the Actinia.

Individual and race development in animals by differentiation.

It will be found, when we describe the development of the higher animals, that a parallelism is observed between the career of each individual and that of the series to which it belongs. The evidence furnished by natural history and palæontology proves that, in the development of animal species, there has been an orderly progress, not so much from those of a lower to those of a higher form, as from the general to the special; a gradual parting out of structures and functions that were once commingled and coalesced, an elaboration which may be attributed either to a melioration of the circumstances under which species were successively forming, or to the innate power possessed by the organic structure itself. Even at the present time our knowledge of the order of geological change is sufficiently exact to enable us to institute an inquiry into the probability of the correctness of each of these hypotheses, upon the principle that, since there is that parallelism between the career of individual development and race development, there should also be an analogy in the physical circumstances under which they have taken place. Among conditions in animal development, two prominent ones may be mentioned; they are the degree of temperature at which the process is carried forward, and the quality or nature of the medium supplied for respiration. No doubt can now exist that, as regards the former, there has been a gradual diminution from the early times, and that, as respects the latter, the quantity of oxygen furnished in the medium of respiration has been increased. It has long been observed, in a general way, that there is a correspondence between the activity of respiration and the degree of animal endowment, both as regards the individual and the race. The provision made for the more perfect conduction of the process from the moment that the embryo exhibits any arterialization of its blood, is always attended with, if it is not the cause of, increasing animal power. The supply of oxygen at the first period is very imperfect, but instrumental means are introduced in succession to increase the amount. When a mere membrane has become insufficient to meet the requirements, branchiæ are resorted to, and these, in their turn, are replaced by lungs. In a double way, therefore, an increased supply is secured, by alterations in the mechanism obtaining it, which gradually becor[illegible]re and more adapted to the end in view, or by variatio[illegible] constitution of the medium which

Differentiation depends on physical circumstances.

Influence of the aerial medium.

furnishes it. Thus, in the development of a mammal, the first and limited supply of oxygen is from the portion contained in the liquids of the ovum; a far more copious one, at a later period, is derived from the placental mechanism; but these subordinate states eventually give place to the direct respiration of the open atmospheric air. As this gradual march in the evolution of the respiratory function is going forward, it is attended by a corresponding development of all the animal capabilities.

So, too, on the great scale with genera and species. In the impure atmosphere of the earliest geological times, it was not possible that energetic respiration could be carried on either by aquatic or by aerial animals. Both may be included in the remark, for it is demonstrable that, on ordinary physical principles, there must ever be a correspondence between the chemical constitution of the atmospheric air and the gas of respiration dissolved in the sea, or other natural waters. Abundant geological evidence is before us to the effect that the entire respiratory medium, both atmospheric and aquatic, has passed through a gradual amelioration, the percentage amount of its irrespirable elements declining, and that of its oxygen correspondingly increasing. The removal of those prodigious masses of carbon deposited as coal satisfactorily establishes this point; and, therefore, as far as that medium is concerned, there is a general resemblance between the conditions under which the entire animal series and the single individual have been placed.

We might include in these remarks the vegetable as well as the animal series; for, as respects flowering plants, it is the special function of their floral or reproductive apparatus to discharge at a particular epoch the functions of an animal in taking oxygen from the air, and replacing it by carbonic acid. There would, therefore, be no cause for surprise if, in that ancient carbonated atmosphere, cryptogamic plants alone could maintain themselves, and that the flowering tribes could only appear after a due change in the aerial constitution, which also gave to hot-blooded animals the opportunity of coming forth. That change, as we have said, consisted essentially in the appearance of a great excess of oxygen gas. Such a superficial examination of the question shows that there is a parallelism between the physical conditions under which the animal series, in the lapse of countless centuries, has been placed, and those to which, in the shorter period of its history, the developing individual is submitted, at least as respects the respiratory function. But it is to be remembered that respiration is the prime function in the animal economy.

As regards the influence of heat, it has been remarked in the preceding chapter that, at the period of the first appearance of organic forms, there was not only a high, but likewise a uniform temperature all over the globe. The evidence establishing this is already given; but if thus, in what might be termed the infancy of the organic

Influence of heat.

series, such a perfect uniformity in the condition of temperature obtained, the same is often observed in the first periods of individual development. The circumstances under which the ovum commences its career, even in the highest tribes, insure for it a perfect relief from every variation of heat. Included in the body of the female, it is cut off from all external causes of disturbance, and kept at the temperature of her body, whatever that temperature may be. In those cases, as in birds, in which the embryo is developed under circumstances of necessary exposure, a strong instinct is called into operation, and, by the incubation of the parent, the necessary uniformity is secured. Again, in other instances, as in the ova of insects, which, by reason of their minuteness and their frequently exposed position, although they may run through their earlier changes with relatively great rapidity, some accomplishing them in the almost uniform warmth of a summer's day, development never does nor can occur until the required condition, even if it be temporary, as to uniformity of temperature, is reached.

These considerations, though not affording an absolute proof that the career of development is guided by the influence of external physical conditions, are sufficiently significant to cast an air of probability over that doctrine; and even if we adopt the view that the developing germ possesses a plastic power, which spontaneously compels it to run forward from stage to stage in a predestined career—if we recall what has already been said respecting that plastic power, that perhaps it is itself nothing more than a manifestation of the remains of antecedent physical impressions, we are really brought back to the same starting-point; and, under any hypothesis, we encounter, sooner or later, as a necessary postulate, the grand doctrine that, directly or indirectly, development is a function of external physical condition.

Epochs of differentiation.

It is not to be supposed that differentiation takes place with equal ease at all periods of the history of organic forms, whether we consider them in the great scale, as constituting the animal series, or on the small, in the individual. There are undoubtedly epochs in each of their histories at which the exertion of an external influence will produce an effect infinitely greater than that which would occur at any other moment. If we may be permitted to use such a mechanical illustration, the career of an organism recalls the flight of a heavy projectile, as a shell, thrown upward, which, at the first moments of its ascent and the last of its descent, pursues its way irresistibly, but when it is at the top of its flight, and the momentum which had been imparted to it is just ceasing, the slightest breath of air, or the exertion of any other insignificant force, will divert it into a path different from that in which it would have gone; and so, in the career of an organism, there *are moments* when forces, which, at another time, would have been unfelt,

can bring on differentiation, and, through it, call into existence new functions, and thereby forever determine a new course, through which it must pass. It is because a due weight has not been given to this consideration that many physiologists have depreciated the influence of external circumstances, or even denied it altogether, for they have assumed that, since we can not produce a more marked change than we do in the way of accomplishing a variation in species by artificially altering the conditions under which they exist, such conditions can have had but little power in bringing them to their present state.

Upon the whole, there can be no doubt that differentiation will occur in a more marked manner according as the exciting impression is made at an earlier period of the organic career. Conversely, the more advanced the organism, the less the probability of differentiation. For this reason it is that striking changes of this kind are rarely witnessed in individual life: they occur chiefly in the first embryonic states, and therefore, for the most part, require for their full manifestation generation after generation. Great organic variations are not, then, to be expected in the individual, though they may be distinctly manifested in the course of time by the race to which it belongs.

Organic changes occur chiefly in the first periods of life.

CHAPTER IV.

OF REPRODUCTION AND DEVELOPMENT.

Relation of Organic Beings: they come from a similar Cell and develop to different Points.—Their Division by Classification is fictitious.—Development and Differentiation.—Homogenesis and Heterogenesis.—They depend on physical Conditions.—The reproductive State closes Development.

Development is from the General to the Special.—Law of Von Bär.—Invariable Sequence in Differentiation.

OF REPRODUCTION: 1st. *By Generation.—Conjugation and Filaments.—The Sperm-cell: its Production.—Spermatozoa.—The Germ-cell: its Production.*

Ovum in the Ovary.—Its Structure.—Corpus Luteum.

Ovum in the Oviduct.—Mulberry Mass.—Germinal Membrane.—The Chorion.

Ovum in the Uterus.—Membrana Decidua.—Placenta.—Development of the Embryo.—Types of Nutrition.—Of Conception.—Of Gestation.—Of Parturition.—Influence of both Parents.

2d. *By Gemmation.—Budding of Plants and Animals.—Of Grafting.—Limit of Gemmation.—Influence of Temperature on Gemmation.*

Alternations of Generation.—Its Explanation.

IN the popular view of the organic world, each individual being is regarded as maintaining an existence independent and irrespective of all others, or, at most, only connected with those of its own race or kind. Without any apparent disturb-

Popular view of the independence of organic beings.

ance of the general system, this or that species or genus might never have existed, since it stands in no relation as being the product of others, nor as having been concerned in giving origin to others.

Its error.

But these superficial conceptions are now to be replaced by others of a far more general and philosophical order, which present to us organic creation under an aspect of sublime grandeur, each class of beings standing in an intercommunication or connection with others—a part of a plan, the manifestations of which are not limited to the forms now existing, but also include those presented by the ancient geological times. These views cast a flood of light not only upon the relations of the various races of life to one another, but also of the human family to them, illustrating the course through which man has hitherto passed, and indicating that through which, in future ages, he is to go.

All organic beings start from the same germ or cell.

Starting from a solitary cell, development takes place, and, according as extraneous forces may be brought into action, variable in their nature, and differing in their intensity, the resulting organisms will differ. If such language may be used, the aim of Nature is to reach a certain ideal model or archetype. As the passage toward this ideal model is more or less perfectly accomplished, form after form, in varied succession, arises. The original substratum or material is in every instance alike; for it matters not what may be the class of animals or of plants, the primordial germ, as far as investigation has gone, is in every instance the same. The microscope shows no difference, but, on the contrary, demonstrates the identity of the first cell, which, if it passes but a little way on its forward course, ends in presenting the obscure cryptogamic plant, or, if it runs forward toward reaching the archetype, ends in the production of man. The diversity of form that is eventually presented depends then, not upon the constitution or aspect of the primitive cell, but upon the influence of the many surrounding agencies to which it is exposed. In one instance, through the interworking of these agencies—perhaps by cessation of one, or perhaps by its increased intensity—development comes up rapidly to a certain point, and there stops. In another case, through change in the conditions, it runs to a farther degree, and there stops. Organic beings are, therefore, the materialized embodiment of what must take place through the action of given forces, of a given intensity, and under given conditions, on an evolving cell; and, though it may suit the purposes of description to classify them into orders, genera, species, or other such subdivisions, it must never be forgotten that these are artificial fictions, and have no real foundation in nature.

The primitive cell passes onward to different points.

The classifications of natural history are fictitious.

Not only is the primordial cell in all instances the same, but the first stages of its career are in all instances identical, and this whether we

consider it in the lowest or the highest cases, belonging either to the vegetable or the animal kingdom. It is a process of repetition or reproduction, cell arising from cell. And here at once we may correct the language so often used—indeed, which we have ourselves just used in this respect, for such terms as high and low are only to be employed in a very restricted sense. The evolving cell gives rise to other cells, but for a period of time no indication is presented as to which of the two kingdoms it is to belong, animal or plant. By degrees, as the development goes on, that point is determined, and so, one after another, the unfolding mass gradually reveals the class, order, family, genus, species, and, finally, its sex and individual peculiarities. In all this there is an evolving of the special out of the general; one after another, peculiarities, which are more and more minute, arise; and thus we are not to regard the progress of development as taking place from the lower to the higher, forms that are more and more complex arising in succession, but we are to regard it as the gradual unfolding of the special from the general.

Development is attended by the gradual evolving of peculiarities.

This career of development applies equally to the case of any individual animal, or any race of animals. Thus man himself, in succession, passes through a great variety of forms, from the condition of a simple cell; these forms merging by degrees into one another, the form of the serpent, of the fish, of the bird, and this not only as regards the entire system in the aggregate, but also as regards each one of its constituent mechanisms—the nervous system, the circulatory, the digestive. Now, on the passage onward, these forms are to be regarded, as has been well expressed, each one as the scaffolding by which the next is built; and just as man, in his embryonic transit, presents these successive aspects on the small scale, so does the entire animal series present them in the world on the great scale. Races of animals are not to be compared as though they were more perfect or lower than one another, but as having advanced more or less in the direction from the general to the special; and therefore, in this philosophical view, we are justified in regarding those animated forms which heretofore have been spoken of as lower in the animal scale as being, in reality, the embryos of those that are higher; and this should lead us to a juster estimate of their relation of value toward one another, since we are very apt to contrast them in that respect. In the case of an individual, as in man, we put at once a true interpretation on the value of the various transitory conditions through which he has passed, estimating these as of but little intrinsic importance; as being, as it were, no more than links in a chain; and this may teach us a more just appreciation of the relations of animal races to one another and to the human species. It may teach us the folly of comparing, as some have endeav-

Analogy of development in the individual and in the race.

Value of embryonic forms.

ored to do, the animal tribes with ourselves; of measuring their instincts with our mental operations; things which are different terms of two different series, and things which are incommensurable.

There are three cases in which we might consider this career. These are, first, in the development of particular organs, as the digestive, respiratory, or circulatory; second, in the development of individual beings, which pass in their onward progress, as we have said, through various forms in succession; third, in the development of species, presenting what have been formerly designated as successive stages of increasing perfection. For all these various cases a single illustration may suffice.

Illustration of the unfolding of the special from the general.

Thus, in the primitive period of life, a single membrane discharges promiscuously and contemporaneously all the various organic functions—it digests, it respires, it secretes; but, a little advance onward, special portions of it are allotted for one and another of these uses, and a localization, a centralization of function ensues, and things that were mixed in confusion become separate and distinct. As the passage onward is made, still farther specializations are introduced, and so on in succession. Thus at the two extremes we may contemplate the single germinal membrane of the ovum, which is discharging contemporaneously every function—digesting, absorbing, respiring, etc.—and the complete organic apparatus of man, the stomach, the lungs, the skin, the kidneys, and the liver—mechanisms set apart each for the discharge of a special duty, yet each having arisen, as we know positively from watching their order of development, from that simple germinal membrane. We must not, therefore, permit ourselves to be deceived by the appearance of complexity they exhibit, since, intricate as may be their construction, they have all arisen through gradual centralization, one duty being separated from another, and having an appropriate mechanism for itself; and so, at last, it comes to pass that even the minutest conditions are discharged by a special part. Thus, in the kidney, the salts are removed by one portion of the structure and the organic constituents by another; yet, even in these utmost conditions of refinement, the primitive condition is at all times ready to be reproduced, and, when driven to it, each of these structures can act vicariously for the others, and discharge for the others their duty.

It is unnecessary for our purpose to multiply instances, since every page of natural history, comparative anatomy, and embryology presents them in abundance; but it may be to the purpose to remark that this doctrine leads to more worthy conceptions of the system of nature; for if we suppose that there has been, in the case of the animal series, a passage from things that are less perfect to things that are more so, *though this* may be agreeable to our own experience, which is essen-

tially tentative, it gives us very base notions of the manner in which natural operations are conducted, since we can not divest ourselves of the idea that such a passage from imperfection to perfection implies trial, verification, and improvement: a process which, though it is suited to the limited knowledge of man, is not in accordance with the precision, perfection, and energy of Nature, and is to be rejected the moment we consider that we deal with the acts of Omniscience and Omnipotence. Moreover, that erroneous view leads to fallacious estimates, both in the animal series and in the individual, of the character of transitory forms, conferring on them too much independence, and therefore too much dignity; for the transitory forms of embryonic life and the forms of animal species are the equivalents of each other.

Base nature of the popular view of the organic world.

Every living being, therefore, springs from a germ, which will develop itself into the likeness of its parent, provided it is submitted to the same conditions through which its parent passed; but if the conditions be changed, it will either take on a new aspect, or if they have become incompatible, it will cease to exist. Similarity of development depends on similarity of condition, as is abundantly proved by such instances as the almost perfect resemblance of the two sides of the body, which, in reality, may be regarded as distinct individual forms. To the proof thus derived from bilateral symmetry as occurring in man might be added such suggestions as arise from the well-known resemblance of twins; and as identity of condition will thus give origin to analogy of development, so we may fairly infer that difference of condition, no matter in what respect the difference may be, will give rise to difference of structure; thus experienced gardeners have shown that the sex of flowers is, to a very great extent, determined by the brilliancy of the light in which they grow. Difference in the supply of nutritive material removes the spines from one plant, or doubles the flowers of another, by changing its stamens into petals, or alters the cycle of career, and makes annuals into biennials.

Career and stoppage of a developing germ depends on external conditions.

As illustrations of the complete changes of form during development, the three following cases may be presented: in *Fig.* 241 are shown the ova of the frog, which are transparent spherical bodies, containing a dark globule. From this, by development, the tadpole, which is a true fish, breathing by gills, arises. The figures represent a side and upper view. After growth has taken place to a certain degree, a change of structure becomes apparent, limbs gradually emerging, and the ani-

Fig. 241.

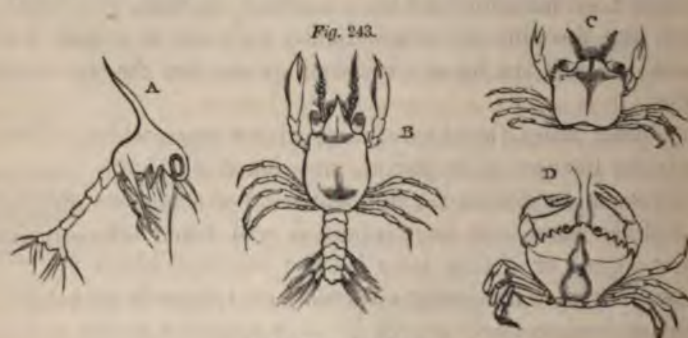
Development of the frog.

Fig. 242.

mal, after passing through an intermediate state, eventually loses its gills and tail, ceases its aquatic, and commences aerial respiration, and shows the aspect, *Fig.* 242, of the perfect frog.

Fig. 243 represents the successive metamorphoses of the Carcinus mænas, or edible crab, as given by Mr. Couch. A represents the animal

Fig. 243.



Development of the crab.

on its emergence from the egg. It has a hemispherical shield on the head and thorax, with a projecting spine, a tail formed of six segments, the two last being joined laterally. The second form, at B, exhibits a great change: the spine has disappeared, the shield is depressed, the eyes on footstalks; there are claws, and the tail is often carried bent under the body. When this shell, like its predecessor, has been cast, the third form, C, is assumed, the transition adapting the animal for walking rather than swimming. The final form, D, is taken on at the next moult, and now development ceases, and growth only takes place.

Fig. 244 illustrates the metamorphoses of a lepidopterous insect, the Bombyx mori, or moth of the silk-worm. From the eggs there arises a caterpillar, which not only possesses the means of locomotion by feet, etc., but also contains within it the rudiments of the organs to be eventually assumed. In this state the insect passes under the name of a larva, because it is covered with a series of teguments,

Fig. 244.

Development of insects.

which, like *masks*, conceal the interior structure. These, in succession, are cast off.

After many such successive castings of the skin, the insect enters into the pupa or chrysalis state. It has no organs of locomotion, and, as it has been, with some degree of imagination, said, becomes an egg again. After resting in this state for a certain time, it bursts its confinement, and assumes the form of an aerial, swift-moving winged insect. This is its imago state.

It will now be convenient to give a more precise definition to terms which have been hitherto used with a certain latitude.

Definition of growth, differentiation, and development.

By the term growth is to be understood the increase in size of a structure, without its assuming any variation as respects the nature of its fabric or of the functions it discharges.

By differentiation is meant an increase involving modification of fabric and the assumption of new function.

By development is meant a differentiation of a higher order, or compound differentiation. Usually it implies growth and differentiation conjointly.

As illustrations of the preceding definitions, it may be said that a crystal grows, its enlargement presenting no structural variation and no new quality. Cells differentiate from their normal spherical form, and, assuming a cylindroid figure, give origin to vascular tissue, the vessels so arising serving for new purposes, as for the conveyance of gases or liquids. A seed develops, for the organism to which it gives rise not only offers continually increasing dimensions, but at all points the origination of novel structures, arising by differentiation from adjacent and pre-existing ones, these new structures having also new functions.

Homogenesis and heterogenesis.

By homogenesis is meant the production of an organism in all respects like its parent; by heterogenesis, the production of an organism unlike its parent.

For the sake of brevity and simplicity, we may suppose that there resides in every germ, and, therefore, in every organism, a principle or quality which governs the collocation or grouping of new parts, the same to which allusion has heretofore been made under the designation of plastic power. It is unnecessary for us here to burden our conceptions of such a power with any hypotheses respecting its nature, it being understood that we use the title of this supposed agent only as an expression of convenience.

An organic molecule the point of origin.

The production of every organism appears, as far as existing observations and experiments go, to be referable to a previously existing organism. This being admitted, generation and reproduction imply, as their starting-point, an organic molecule. Such a combination, furnished with nutrition, grows, its plastic power

grouping the new material. But such a growth can not take place to any extent without a variation being encountered in the surrounding conditions, and the instant that this occurs, differentiation ensues as its necessary consequence. Growth under changed circumstances is then differentiation. If the order of variation, as regards condition, is exactly the same in the case of two growing and differentiating combinations, their career of development will be exactly alike, and the forms they will present at the same epoch of their course will be the same. According as the career is short, the probabilities of identity are greater, since the chances of variation, which might be encountered in the two cases, are less. But where the career is more protracted, and many conditions in succession must be encountered, it can not happen that there will be an exact resemblance in the course of two organic combinations, and therefore there never can be an absolute identity in the aspect of any two resulting forms.

Condition for similarity of development.

The general result of every development is heterogenesis. No parent organism ever reproduces another absolutely like itself, unless it be in the lowest developed types, in which the opportunity for change is at a minimum. Homogenesis is only approached as the conditions bringing on differentiation approach similarity; it therefore sinks into a special case coming under a more general law, and, indeed, speaking with exactness, we might say that in the natural world it never occurs, the prevalent notion which regards it as the rule and heterogenesis as the exception being altogether illusory. Every grade of organism, vegetable and animal, furnishes us with examples of this truth. Let us look for a moment at the highest tribes; and in them reproduction never takes place except by pairs of individuals of different sexes. Rigorously, therefore, the births should also be by pairs of different sexes. Moreover, if it be necessary in these general and superficial considerations, let us direct our attention to the special case of man. The infant necessarily differs from one of its parents in sex, and from both in size, weight, endowments, and physical attributes. It is like neither of them. The popular notion may suggest that a closer resemblance will be reached, perhaps, after the lapse of thirty or forty years, when a nearer approach to the form of one of the parents may be offered with elements incorporated from the lineaments of the other; but even in this case a rigorous examination compels us to admit that like has not produced like.

Development commonly tends to heterogenesis.

Reflecting on this popular illustration more profoundly, we discern wherein the error consists. Instead of comparing cycles of process, we have been blundering with isolated forms, which arise at different epochs therein. Without going into tedious details, man presents, as regards the most important of

Cycles of process to be compared, and not individual forms.

his constituent structures, his nervous system, the successive characteristics of an avertebrated animal, a fish, a turtle, a bird, a quadruped, a quadrumanous animal, before he assumes the special human characteristics. This is his cycle of life, and it is the same cycle in one case as in another.

But the moment that our view is thus enlarged, we see that it is not the individual with which we should deal, for an individual we can scarcely define, since he is continually differing from himself. It is with a cycle of proceeding, or a course of operations that we are engaged, a series of forms being the outward manifestation of the succeeding periods of that cycle or course.

An infant, though unlike both its parents in form, has run through a career like that passed through by them both. Sexual differentiation, which indeed is one of the last differentiations occurring, offers no exception to the truth of this remark. The similitude lies in the career, not in the form taken at different epochs.

The reproductive state closes development.

The essential principle, then, is, not that an organism produces a like organism, but it produces a germ which, being placed under similar circumstances, passes through a like career of development, and at successive periods offers an orderly series of forms. The career is commonly observed to close as soon as the capacity for reproduction is assumed. Hence, in every organism, the assumption of the reproductive state is the signal that the end of development is at hand.

It does not plainly appear what are the circumstances which give rise to the assumption of this capacity; nevertheless, it may take place at any moment of the career. In the Volvox globator it occurs almost at the close of the first stage, for the germ only reaches the condition described hereafter as the mulberry mass when it becomes capable of reproduction; but in man the developing organism has a long journey to perform beyond this first step. Except in the condition here dwelt upon, he differs in no respect from his humbler comrade at this point. The tendency to a gliding off into the reproductive phase is in him repressed, and therefore differentiation and development continue to go on.

All the parts of an organism arise from a common central origin.

During the development of any new organism, the new parts uniformly arise from the old ones; they are not built from foreign materials depositing themselves upon new centres, but are educed by the unfolding, enlarging, and modeling of parts already existing. An organism is not developed as we enlarge a house, by building part to part, but it all expands from one common or single centre. As the sphere of its expansion becomes greater, the opportunity arises for devoting different regions to different uses, and thus offices which were confusedly intermingled become separated out, and,

as, in social undertakings, the division of labor gives greater perfection to the work, so in this, functions which, because they were blended, were imperfectly discharged, now assume precision and power, because they are disentangled from what were perhaps countervailing conditions.

Law of Von Bär.

By these considerations, we are gradually led to the general law of development, first recognized by Von Bär, and passing under his name. This is somewhat obscurely enunciated in the following terms: "The heterogeneous arises from the homogeneous by a gradual process of change." By this it is meant that, in the process of development, the stages are not from forms that are of a degraded to those of a higher type, but that from the general the special, which was therein included, is gradually evolved.

Invariable sequence and differentiation.

In conclusion of these preliminary remarks on reproduction, it may be observed that, even in the highest and most elaborate types, the causes which bring on differentiation follow each other in such a predetermined sequence, that the whole phenomenon might be said to be under the dominion of mathematical conditions. As a striking instance of this may be mentioned, in the case of man, the numerical equality of the sexes; and that this singular result is determined by the alternate preponderance of conditions which are otherwise nicely balanced, is shown by the interesting instances occurring among insects of dimidiate and quadrate hermaphroditism, in the former of which the resulting insect is of different sexes on the two sides of its body, and in the latter the male and female portions are quadrantally arranged. If the left side of the head and thorax are those of a male insect, the right half of the abdomen is of the same kind, the intervening portions being of the other sex. The neuter state might even be imagined to arise from the more precise blending, balancing, and confusing of such conditions as here give evidence of an incipient tendency to separate from one another.

Divisions of reproduction.

In the farther discussion of reproduction we shall find it conveniently considered under two distinct divisions; first, generation; second, gemmation. Our attention may, then, be profitably directed to the singular facts known under the designation of alternation of generations. As illustrations of the terms here employed, it may be stated that the production of a seed and the development of a plant therefrom are to be considered in connection with generation, and that the obtaining of new plants and trees by budding and grafting, and the production of many new hydras by their sprouting forth from an old one, are to be considered under gemmation. By the alternation of generations is meant that an organism, A, will give rise to a second one, B, wholly unlike itself, and that this second organism, B, will give rise to a *third*, C, unlike itself, but C shall resemble A. This singular condition

of things will be shown to originate in the periodical alternation of generation and gemmation respectively.

1ST. OF GENERATION.

Reproduction by generation is accomplished on two different types: 1st. By the conjugation of two similar cells; 2d. By filaments.

In the first, that is, by the conjugation of two similar cells, a third body, called a sporangium, results. Of this process there appear to be three different modifications: 1st. The two similar conjugating cells discharge their endochrome, or coloring material, each voiding itself completely, and the sporangium arises from the mixture; 2d. A dilatation forms on the point of union of the two conjugating cells, and into this dilatation the endochromes of both cells are passed; 3d. The endochrome of one cell is wholly retained, and that of the other is added to it, the one becoming void, and in the other the sporangium being produced. This, occurring in the lowest vegetables, among which it was for a long time supposed that the type of reproduction is totally different from that of flowering plants and animals, presents us with the first traces of what is eventually displayed as difference of sex.

Three modifications of conjugation.

This shadowing forth of the difference of sexes is illustrated in a very instructive manner by the Zygnema quininum, a fresh-water conferva. Its manner of growth is what has been already described in the case of the Conferva glomerata, *Fig.* 231. In the annexed *Fig.* 245 is represented at A the process of growth by the subdivision of cells, *a b c* representing three such cells, the middle one, *b*, being in the act of subdivision. At B two threads are in the act of conjugation. The endochromes of both are spirally arranged, and dilatations reaching from one to the other are here and there seen. At C the endochromes of one thread, *a*, have wholly passed over to the other thread, *b*, and the round bodies, or spo-

Fig. 245.

Development and reproduction of Zygnema quininum.

rangia, are the result. It is this passage from one thread to the other which betrays the first indications of sex.

In the second, that is, by filaments, two cells are again necessary, which, differing in construction and also in function, are designated the sperm-cell and germ-cell respectively. Of this type there are two modifications: 1st. Reproduction by moving filaments, as presented in the higher algæ and ferns; 2d. By elongating filaments, as in flowering plants. The moving filaments, which were discovered in the case of animals soon after the introduction of the microscope, were regarded as animalcules, and passed under the designation of spermatozoa. The germ which arises in the first of these modifications is, in the lower tribes, unprovided with any nutritive supply; in the higher, a stock of food is prepared for it by the parent. In the second, the sperm-cell, or, as it is frequently termed, pollen grain, does not produce a moving filament, but elongates itself into a delicate tube until it reaches the germ-cell. A stock of nutritious matter is placed around the resulting embryo, and this is the ordinary construction of seeds.

Two modifications by filaments.

Restricting our description to the case which more immediately interests us, we shall first consider the mode of origin and nature of the sperm-cell and its filaments in animals, and then of the germ-cell and its process of development when fertilized.

1st. *Of the Sperm-cell.*—The testes are the organs in which the sperm-cells and filaments arise in man. They are of an ovoid form; each is covered with a white envelope, the *tunica albuginea*. A serous membrane, folded as a shut sac, overlies this tunic. From the inner surface a number of delicate projections arise, which divide the organ into several compartments. In these compartments are lodged lobules arising from the tubuli seminiferi and their supplying blood-vessels. There are about 450 lobules in each testis; their shape is conical, the diameter of the tubes of which they are composed about the $\frac{1}{200}$ of an inch. The total length of this tubular structure is about three quarters of a mile. Before the tubuli of each lobule reach the rete testis, they cease to be convoluted, and bundles of them, uniting into larger vessels, are designated tubuli recti. In the rete testis there are from half a dozen to a dozen of these tubes, which variously anastomose with one another and divide. They empty into the vasa efferentia, which, from being straight, become convoluted, a series of cones arising, which together form the globus major of the epididymis. This is a convoluted canal, of about twenty feet in length, which, descending, receives beyond its globus minor the vasculum aberrans. It then empties into the vas deferens.

Production of sperm-cells by the testes.

Fig. 246, human testis: *a*, testis; *b*, lobes; *c*, tubuli recti; *d*, rete

Fig. 246.

The testis.

vasculosum; *e*, vasa efferentia; *f*, coni vasculosi; *g*, epididymis; *h*, vas deferens; *i*, vas aberrans; *m*, branches of the spermatica interna of the testis and epididymis; *n*, ramification on the testis; *o*, arteria deferentialis; *p*, anastomosis with a branch of the spermatic. (Arnold.)

The secretion of the testis must be taken for examination from the vas deferens or epididymis, before it has been mixed with the fluid of the prostate and Cowper's glands, or with mucus. It may be mingled with a little albumen or serum for the purpose of dilution, and, when examined with a power of 500 diameters, exhibits multitudes of moving bodies. These are the seminal animalcules, or spermatozoa. Among them are to be seen, here and there, round granular bodies, the seminal granules. These, with the spermatozoa, are sustained in a clear and transparent liquid. The examination of these different constituents is conducted with difficulty, since they can not be separated from one another by means of filtration. The spermatozoa arise from the seminal granules.

The spermatozoa are found in the spermatic fluid of all animals after puberty, their form being different in different classes and species. Generally they may be described as consisting of a little oval-shaped head, from which a delicate filament or tail projects. Spermatozoa, description of.

The motion of the spermatozoa is accomplished by means of their filament. It takes place in different ways, sometimes the filament vibrating like a whip, sometimes rotating like a screw, and sometimes a spinning round, as it were, upon a pivot, occurs, the filament having been coiled like a watch-spring. The rate of motion seems under the microscope to be rapid; it is, however, estimated at an inch in thirteen minutes. In man, their entire length may be estimated at about the $\frac{1}{500}$ of an inch, the length of the head being about the $\frac{1}{5000}$, and its breadth the $\frac{1}{10000}$. They continue to exhibit motion in birds for fifteen or twenty minutes after death; in cold-blooded animals even after days. They withstand, for a time, the action of solutions of sugar and salt, but are destroyed at once by alcohol and dilute acids, Human spermatozoa.

which appear to affect their organization. Strychnia, opium, and hydrocyanic acid likewise stop their motions, but without causing any change in their form.

The production of spermatozoa is best studied in the case of birds. Spermatozoa in birds. For this purpose Wagner recommends that one of the order of Passeres be taken in the pairing time. The condition of the testes indicates the state of evolution of the spermatozoa. In winter those organs are of the size of a pin's head, but in spring they have increased twenty or thirty fold. Exteriorly they exhibit convolutions like those of the brain, and contain granules and seminal globules. After pairing time is over, they relapse to their original diminutive state. The seminal globules appear to be derived from the epithelial cells lining the tubuli seminiferi. They are developed into what are termed primary cells, each of which contains a number of secondary cells or vesicles of evolution. In the interior of these vesicles the spermatozoa originate, as a derivation or development from the nucleus, each vesicle giving rise to one spermatozoon. Evolution of spermatozoa. When this has reached perfection, the vesicle deliquesces and sets it free. There are from one to twenty vesicles of evolution in each primary cell. In birds the filaments may be retained for a length of time in the primary cell after deliquescence of the vesicle, but in mammals, as soon as the filament is mature it escapes. In the former case the filaments aggregate into bundles, but they break up into individuals when the primary cell deliquesces.

Fig. 247.

Development of spermatozoa.

Fig. 247, spermatozoic filaments, developing in Certhea vulgaris: *a*, seminal granule; *b*, cyst, with two vesicles of evolution, many granules, and a bundle of spermatozoa; *c*, oval cyst, with spermatozoa coiled up. (Wagner.)

Of the formation of spermatic filaments Dr. Burnett gives an account somewhat different from the preceding. According to him, "the morphological changes in the sperm-cell preceding the formation of the spermatic filaments are identical in their character with the changes in the ovum which are antecedent to the formation of the new being. When the generative function begins to be developed, the character of the epithelial cells lining the tubules is modified. The cells pass to a higher degree in function, but do not undergo any change in structure, except a slight increase in size. In this condition they divide and subdivide, by a process similar to the segmentation of the yolk, until they are entirely converted into a mulberry mass. A liquefaction of the segmented contents into a minute granular blastema then ensues, and from this the spermatic *filaments* are developed. In the Plagiostomes, Dr. Burnett was able to

observe the disappearance of the mulberry mass, and its replacement by a fasciculus of spermatic filaments, although the exact metamorphosis by which the granular cellular mass formed the bodies of the spermatozoids could not be detected. The spermatic filaments, Dr. Burnett thinks, are not formed, as stated by Kolliker, by a deposit from the contents of the sperm-cell or nucleus, but by an elongation of the nucleus itself. The body of the spermatozoid is developed from the cell, while the tail is probably subsequently formed by an accumulation of minute particles." (Kolliker, Am. ed., p. 625.)

In man, the production of spermatozoa commences between the fourteenth and sixteenth year, the time of puberty, and continues until the sixty-fifth or seventieth, or even much longer. This period of commencement is marked by a great change in the physical and moral constitution.

The spermatic fluid of mule animals contains no spermatozoa. This fact has been established in an interesting manner by Wagner in the case of birds, of which many of those which are domesticated readily cross. There can be no doubt that these bodies are the essential portion of the fluid, and that it is their action upon the ovum which establishes its fertilization.

There has been much controversy whether the spermatozoa present traces of organization, properly speaking. Though it is convenient to designate their dilated portion as the head, and the filament as the tail, it has never yet been established that any thing answering to a true structural arrangement exists, and, upon the whole, it may be concluded that the appearances which have been by some supposed to indicate organization are, in reality, only an optical illusion.

2*d*. *Of the Germ-cell.*—In mammals the female reproductive apparatus consists essentially of the ovaries, oviduct, and uterus.

Female reproductive apparatus.

The ovaries are two ovoid bodies situated on either side of the uterus. They consist of a stroma in which vesicles are imbedded: these vesicles give origin to the ova. In the manner to be presently described, the ova, being received at the fimbriated extremities of the Fallopian tubes, those tubes being therefore appropriately termed oviducts, are carried into the cavity of the uterus.

The catamenia.

At the time of puberty in the human female, which occurs between the 14th and 16th year, a physical and moral change takes place, answering to that which has been already alluded to as occurring in the male. From this period a sanguinolent discharge makes its appearance monthly: it is the catamenia. The interval from time to time is commonly estimated at four weeks; it varies, however, with individuals, and it is said also with climates, the discharge occurring in the hotter more frequently, and in greater quantity. It is essentially blood, which has been deprived of its quality of coagulating by inter-

mixture with acid mucus of the vagina. So long as these periods continue, the individual possesses the reproductive power, the first appearance of the catamenia indicating the capacity for conception, and the disappearance, at about the 45th year, its end. During gestation the catamenia are suspended, and, indeed, it is this event which is usually taken as the indication that conception has occurred.

The periodical occurrence of this discharge in the human female, though more frequent, is essentially the same as the periodically occurring heat of other animals, which is also attended with a sero-sanguinolent discharge. In other respects, likewise, the analogy is maintained, for in those animals, the appearance of this discharge and its attendant phenomena constituting an indication of a simultaneous capacity for conception, in women the same thing holds good, conception occurring in them at the time of the close of the menstrual discharge.

I. *Ovum in the Ovary.*

The ovary is the organism in which the ova are prepared, these bodies arising in the following way:

Production of ova.

In the stroma of the ovary there occur at a time ten, twenty, or many more cells, which have received the designation of Graafian vesicles or ovisacs. These originate in the interior of the ovary, and, as they become perfected, pass to its surface, presenting themselves thereupon as prominences which are covered over exteriorly with peritoneum. Each of these vesicles has a membranous envelope connecting it with the substance of the ovary exteriorly, and covered interiorly with a layer of nucleated cells, designated membrana granulosa. It is filled with a fluid in which multitudes of granules float, and in its centre is the ovule. This, as it becomes mature, is pushed up toward the surface of the ovisac by an accumulation of liquid in the lower part thereof, and is so brought into close relation with the membrana granulosa at the place where it is upon the surface of the ovary. At this point there collects on the ovum a zone of granules, to which the designation of discus proligerus is given.

Fig. 248, transverse section through the ovary of a woman dead in the fifth month of pregnancy: *a*, Graafian follicle of inferior, and, *b*, of superior surface; *c*, peritoneal lamella of ligamentum latum, continued upon the ovary, and coalescing with, *d*, the tunica albuginea: in the interior two corpora albicantia (old corpora lutea) are visible; *e*, stroma of the ovary. (Kolliker.)

Fig. 249, section of the Graafian vesicle: 1, stroma of ovary, with blood-vessels; 2, peritoneum; 3 and 5, layers of the external coat of the Graafian vesicle; 4, membrana granulosa; 6, fluid of the vesicle; 7, granular zone, or discus proligerus; 8, the ovum. (Von Bär.)

Fig. 248.

Section of ovary.

Fig. 249.

Section of Graafian vesicle.

Fig. 250.

Ovum.

Fig. 250, ovum of the sow: 1, germinal spot; 2, germinal vesicle; 3, yolk; 4, zona pellucida; 5, discus proligerus; 6, adherent granules or cells. (Barry.)

Description of the ovum.

The diameter of the human ovum varies from the $\frac{1}{120}$ to the $\frac{1}{240}$ of an inch. It consists of an exterior transparent membrane, the $\frac{1}{2500}$ of an inch in thickness, which, when compressed for the purpose of examination, appears like a diaphanous circle, and hence called zona pellucida. Within this zone, and inclosed by it, is the yolk, a granular material suspended in or intermingled with fluid, the granules being of different sizes; those near the pellucid zone are the largest. For the most part, the yolk consists of albumen and oil globules. Its condition, as regards liquidity, varies in different animals; in some it is almost a soft solid, so that, when water percolates through the zona pellucida, it isolates the yolk by surrounding it on all sides, and parting it off from the zone. Within the substance of the yolk is a distinct cell, the germinal vesicle, which gradually makes its way from the interior to the place of peritoneal contact. As it advances to perfection, it consists of a delicate spherical membrane containing a liquid, in which granules are suspended. Upon that portion of it nearest to the place of peritoneal contact is its nucleus, the germinal spot, about the $\frac{1}{8000}$ of an inch in diameter, and consisting of yellow granules.

Fig. 251.

Diagram of Graafian vesicle.

Fig. 251, diagram of a Graafian vesicle and ovum: 1, stroma of ovary; 2, 3, external and internal tunics of the Graafian vesicle; 4, cavity of vesicle; 5, thick tunic of the ovum or yolk-sac; 6, the yolk; 7, the germinal vesicle; 8, the germinal spot.

The most mature ova are nearest the surface of the ovary, but are separated from its peritoneum

by a thin, fibrous layer of stroma. The Graafian vesicle is, therefore, the parent of the ovum. Periodically, as development is going on, the Graafian vesicle bursts, and the ovum is set free. This effect arises, in part, from the circumstance that, the space between the vesicle and ovum being filled with cells, those near the surface of the ovary disappear, and an albuminous liquid, which accumulates below, pushes the ovum up. This extrusion of ova occurs even in childhood. The ovisac, or Graafian vesicle, thus changed into a follicle, is gradually filled up, its walls wrinkling, and red-colored material, arising from the membrana granulosa, being deposited in it until it is almost filled. This deposit gradually turns yellow, and is eventually composed of cells interiorly, and fibres arising therefrom exteriorly. When the deposit is completed, a stellated cicatrix is observed in its midst. The yellow body thus arising passes under the designation of corpus luteum. If impregnation does not occur, the yellow substance forms to but a small extent, and after a time disappears. It is relatively more abundant in animals than in women. Attempts have been made to use the indications of the corpus luteum for determining the question of pregnancy. The following points are presented by Dr. Dalton as offering characteristics by which the corpora lutea of pregnancy and menstruation may be distinguished: "The corpus luteum of pregnancy arrives more slowly at its maximum development, and afterward remains for a long time as a noticeable tumor instead of undergoing rapid atrophy. It retains a globular or only slightly flattened form, and gives to the touch a sense of resistance and solidity. It has a more advanced organization than the other kind, and its convoluted wall is much thicker. Its color is not of so decided a yellow, but of a more dusky hue, and if the period of pregnancy is at all advanced, it is not found, like the other, in company with unruptured vesicles in active process of development."

Corpus luteum.

Fig. 252, corpora lutea of different periods: *a*, corpus luteum two

Fig. 252.

Corpora lutea.

days after delivery; *b*, corpus luteum of about sixth week after impregnation, showing its plicated form at that period; 1, substance of ovary; 2, substance of corpus luteum; 3, grayish coagulum in its cavity; *d*, in

the twelfth week after delivery. (*a* and *b*, Dr. Patterson; *d*, Dr. Montgomery.)

II. *Fertilized Ovum in the Oviduct.*

Such being a description of the ordinary or unfertilized ovum, we have next to follow the changes which ensue if fertilization has taken place.

The spermatozoa having become enveloped in the pellucid zone or passing through it, the ovum is received by the fimbriated extremities of the Fallopian tube, along which it is carried by peristaltic contraction or ciliary motion. The first change which takes place in it is the disappearance of its germinal vesicle and germinal spot. This disappearance is, however, stated by some to be preceded by a development of cells originating in the nucleus or germinal spot; nor is it the result of fertilization, since it occurs in the unimpregnated ovum. The cells of the membrana granulosa, which surround the ovum, become first of a conical shape, but their rounded form is resumed on passing into the tube.

Changes of the fertilized ovum in the oviduct.

Fig. 253.

Ovarian ovum.

Fig. 253, ovarian ovum of dog, exhibiting the elongated form and stellate arrangement of the cells of the discus proligerus round the zona pellucida.

Fig. 254, same ovum after the removal of most of the club-shaped cells.

Fig. 254.

Ovarian ovum.

The yolk is next observed to contract so as to leave a clear space between it and the zona pellucida. As the passage along the tube is taking place, the zona assumes a coating of albuminous material, which is what is called in birds the white of the egg. It eventually becomes the chorion. Meantime, after the disappearance of the germinal vesicle, a new cell, the embryo cell, arises, and this undergoes subdivision or segmentation, an effect in which the yolk itself presently becomes involved, each new or daughter embryo cell so arising assuming a part of the yolk. A constant process of bisection is thus established, the yolk dividing first into two portions, then into four, eight, sixteen, etc., each division containing a nucleated cell. At this period may be seen the spermatozoa involved in the zona pellucida, and, as the process of bisection goes on, the mass assumes a mulberry aspect, and finally becomes granular. This is, for the most part, finished by the time the ovum enters the uterus.

The mulberry mass.

Fig. 255, ova of the dog in various stages: *a*, from the oviduct, half an inch from the uterus, spermatozoids being in the pellucid zone, the yolk

bisected; *b*, cells of tunica granulosa have disappeared, and the yolk is in four segments; *c*, continued advance in segmentation; *d*, the zona has become thicker, and the segmentation more complete; *e*, ovum burst by compression: some of the segments have escaped; each shows a bright spot or vesicle.

Fig. 255.

Segmentation of ovum.

Fig. 256, cleavage of the yolk after fecundation: *a*, an ovum of Ascaris nigrovenosa, the yolk of which is divided into two equal portions; the upper portion contains a cell with a large nucleus, the lower a similar cell with two small nuclei; *b*, ovum subdivided into four portions; *c*, the subdivision has reached sixteen, each possessing a mono-nucleated cell; *d*, ovum of Ascaris acuminata, showing the stages of subdivision, the portions becoming very small; *e*, the portions preparing to be moulded into the young worm. (*a*, *b*, *c*, Kolliker; *d*, *e*, Bagge.)

Fig. 256.

Segmentation of ovum.

As the ovum is about to enter the uterus, each portion which has arisen from the segmentation of the yolk has become a perfect cell. This cell formation having been accomplished at the surface of the yolk first, the cells there begin to coalesce into a membrane, with an aspect like that of hexagonal pavement epithelium, and, as the change passes toward the centre, the cells, as they form, come toward the membrane and thicken it, leaving a clear liquid within. In this manner a secondary vesicle *forms* within the zona pellucida: it is the blastodermic vesicle: it is the

orary stomach of the embryo. Its wall constitutes the germinal brane, upon which the embryo arises. New cells being constantly d, the membrane increases in thickness; and here it may marked that, in most types, the yolk is to be considered esenting two portions—the germ-yolk and the food-yolk; the for- being immediately employed in the development of the embryo, and atter being a stock for more advanced supply. In mammals, for n other means of nutrition are quickly provided, the food-yolk is im- eptible, and, moreover, in them the albuminous coating of the zona cida is small; but in birds, the embryo of which has to be nourish- dependently of the parent, the quantity is necessarily large. As we said, this albuminous covering and the zona together constitute the on, the exterior of which presents a rugged aspect, from the appear- of absorbing radicles, which, becoming imbedded or dove- l in the deciduous membrane, presently to be described, lishes the necessary connection for tuft nutrition, and thereby ob- ng albumen from the parent.

The germinal membrane.

The chorion.

III. *Fertilized Ovum in the Uterus.*

'hile the ovum is passing through the Fallopian tube or oviduct, it ns a coating of albuminous material outside of its zona pellucida, as been said. This coating becomes the means of attachment to the is, and thereby of the absorption of nutriment in the following way. e outside surface of the incipient chorion presents a layer of cells, soon after assumes a fibrous structure. In this condi- tion the ovum makes its appearance in the uterus, on the interior of the surface of which the mouths of a great number of follicles open. These follicles are not unlike those which the stomach presents. Their general appearance is illustrated by *Fig.* 257; *d*, cæcal terminations of glands; *e*, their tubes; *a*, mouths on interior of uterus. The constitutional disturbance which is at this time taking place, enhanced by the presence of the ovum in the organ, at once increases its vascularity; the follicles become larger, cells are abundantly developed in them, and the uterine cavity is filled with a liquid containing many nucleated cells. This plastic semi-fluid material receives the fringes of the villous coat of the chorion, which are now being developed; and these even find their way into the mouths of the glandular tubes; from this exudation or secretion the membrana decidua forms, though by some it is

Uterine nutrition.

Fig. 257.

Uterine tubes.

Formation of membrana decidua.

represented as being a metamorphosis of the mucous membrane itself. Meantime the ovum is itself coated over with a corresponding membrane, designated membrana reflexa, because it was believed by Mr. Hunter to originate in the circumstance that, when the ovum reached the uterine mouth of the Fallopian tube, it there encountered the proper membrana decidua, and, not perforating it, but bearing it onward, gathered a fold, covering, or envelope, which, from its having thus been formed by a reflexion, was appropriately designated by the term specified. It is, however, now admitted that this description of the formation of the membrana reflexa is erroneous, for in reality the ovum is at no time on the outside of the mucous membrane, which is continuous from the cavity of the uterus through the Fallopian tube. The following, therefore, seems to be the more correct description. The presence of the ovum gives rise to an increased development of cells, which rapidly spread around it, and coat it all over, their points of origin being those portions of the uterine mucous membrane with which the ovum is in contact. In this way it receives its deciduous envelope, which, participating duly in its growth, is at the end of the third month in contact with the uterine decidua all over.

At the stage we are now considering, the nutrition of the embryo is conducted in a special but very temporary way. The yolk of the ovum has no stock of food to maintain the nutritive processes beyond the brief space which transpires in the passage through the Fallopian tube. The duty of nutrition is at this moment assumed by the villous coat of the chorion, which absorbs fluid exuding from the uterine decidua very much after the manner of the spongioles of a plant; but almost immediately the necessity arises of diverting more directly the albumenoid material to the quickly-growing embryo from the yolk-bag, to which it would have gone, and this new destination implies the introduction of new channels of transport, which, under the form of a vascular apparatus, are now provided.

The placenta.

About the close of the second month, a proper vascular apparatus for the combined purposes of nutrition, secretion, and respiration makes its appearance: it is the placenta. Its origin is in the little blood-tubes which form in the tufts of the chorion, in man at one point, in ruminants simultaneously at several, giving rise in the former case to one organ, the placenta, as has been said, in the other to many such, or, at all events, to one of a composite structure, the cotyledons. The fœtal vessels thus arising in the villi of the chorion become intermingled with vessels contemporaneously arising from the uterus; and though, in some cases, this intermingling is less complicated, so that the maternal and fœtal portions are separable, in man the internetting is complete, the principle being to bring the fœtal vascular tufts in such a

relation with the maternal blood-sinuses, by the tufts dipping down or being enveloped therein, that the completest contact and facility of exchange, but not of intermixture, may be insured. Things are arranged in such a way that the maternal and fœtal blood do not intermingle, each being confined in vessels of its own, through the thin walls of which nutritious matter may pass and excrementitious matter repass. Every fœtal tuft has a deciduous layer upon it, and the blood brought by the curling arteries of the uterus furnishes to the fœtus its oxygen, and receives back carbonic acid, with other excrementitious matters. In this respect, respiration is carried on by the aid of a mechanism which answers to the gills of fishes, the maternal arterial blood standing for the aerated water; but, besides this, the tufts have another duty to discharge—the obtaining of albumenoid material from the maternal blood. The placental mechanism is therefore much more perfect in its action than the tuft mechanism which preceded it.

Functions of the placenta.

The germinal membrane, formed as has been described, already exhibits at one spot an opaque area of a roundish shape, consisting of cells and granules. To this the designation of germinal area is given. At this area the membrane next becomes divisible into two laminæ, and eventually throughout its whole extent, as seen in *Fig.* 258. Of these laminæ, the exterior, which is nearer to the zona pellucida, is the serous layer. It is the raised membrane of the figure, and in it are to be developed the nervous and muscular systems of the embryo. The interior is designated the mucous layer, and from this arise the digestive organs.

Change in the germinal membrane, and production of layers.

Fig. 258.

Fig. 259.

The germinal area by degrees loses its circular form and becomes oval, its central portions clearing off and giving rise to the area pellucida. Around this the opacity is increased, and in it blood-vessels appear; hence to this dark circle the designation of area vasculosa is applied. In the pellucid zone is next seen a delicate line, the primitive groove, *Fig.* 259. It occurs in the serous layer only, is wider at one end than at

The primitive groove and dorsal laminæ.

the other, the wider part being destined for the head of the embryo. On each side of the primitive groove two oval areas of cells emerge: they are the dorsal laminæ. They rise up to cover in the primitive groove, so as to convert it into a tube, with three bead-like swellings at its wider end, the elements of the prosencephalon, mesencephalon, and epencephalon, *Fig.* 260. The explanation of this and the preceding figure have already been given on p. 293. On the internal part of the lamina nervous matter begins to form, the rudiment of the cerebro-spinal axis. In the bottom of the groove is the trace, chorda dorsalis. The groove itself, converted into a tube, constitutes the central canal of that axis, its completion into the tubular shape occurring first in the middle, and then up and down. The form of the lateral masses varies as development goes on.

Fig. 260.

Origin of the brain upon the spinal cord, magnified 8 diameters.

Chorda dorsalis—vertebræ and vascular system.

A line of cells running lengthwise in the primitive groove is the origin of the chorda dorsalis, on which the rudiments of the vertebral column appear. In the amphioxus and myxenoid fishes development in this direction stops at this point, the chorda dorsalis being the permanent structure. The vertebræ now emerge under the aspect of square plates, and the dorsal laminæ, prolonging themselves outward and downward, as it were, by an offshoot, produce the ventral laminæ, which close in the abdominal walls, and so form the boundaries of the trunk. Simultaneously a new layer of cells arises between the serous and mucous layer of the germinal membrane, at the area vasculosa, and in this intercalated lamina the vascular system forms and blood corpuscles appear, capillary vessels arising from the coalescence of nucleated cells, the touching ends of which become pervious. As the process goes forward, a network of such vessels is constructed, and it is to be particularly remarked that this takes place and that the blood is in circulation prior to the existence of the heart. Around the extending blood-vessels or vascular area runs a circular capillary called the terminal sinus in the first stage of the process, but this disappears as the vessels extend all over the germinal membrane. The extension of these vessels is in part accomplished by the cells from which they have arisen elongating themselves into processes.

Fig. 261, first appearance of blood-vessels in vascular layer of germ-

Fig. 261.

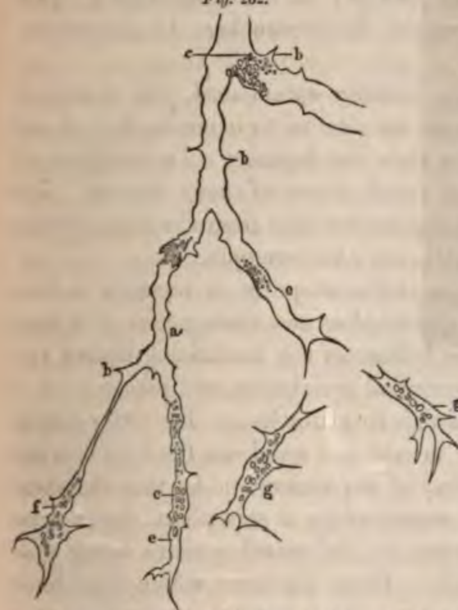
Production of vessels.

inal membrane of a fowl at thirty-sixth hour of incubation. (Wagner.)

The formation of vessels from the coalescence of nucleated cells, the touching ends becoming pervious or elongating, is continued to a much later period of development, as is demonstrated by *Fig.* 262.

Capillary lymphatic from the tail of the tadpole: *a*, membrane; *b*, processes formed by it; *c*, remains of the contents of the cells forming these vessels, in which nuclei are concealed; *e*, cœcal terminations of the vessels; *f*, one of these terminations still recognizable as a formative cell; *g*, isolated formative cells about to join with actual vessels, magnified 350 diameters. (Kolliker.)

Fig. 262.



Production of vessels: capillary lymphatic, magnified 350 diameters.

It is at this time that nutrition by cells ceases, and vascular nutrition commences, as previously described. The embryo has now become too large for promiscuous cell nutrition to answer; moreover, development is required to take place at different rates at isolated and special points. The formation of the amnion coincides with these events.

Development of the heart.

The heart appears first as a canal or tube, arising in the vascular layer from a columnar mass of cells, of which the inner ones have deliquesced to form a tube. This then becomes tri-chambered, containing an auricle, a ventricle, and the bulbus arteriosus, *Fig.* 263, of which a description is given on p. 135. Subsequently the auricle and ventricle are each divided by septa, that in the ventricle being commenced about the fourth, and finished about the eighth week. The auricular septum is not completed until after birth.

Fig. 263.

Rudimentary heart.

Fig. 264, page 530, shows the human heart at about the fifth week: A, the heart opened on the abdominal aspect; 1, the bulbus arteriosus;

Fig. 264.

Fœtal heart.

2, 2, two aortic arches, uniting posteriorly to form the aorta; 3, the auricle; 4, the opening from the auricle into the ventricle, 6, which is laid open; 5, the septum rising from the lowest part of the cavity of the ventricle; 7, the vena cava inferior: B, view from behind; 1, the trachea; 2, the lungs; 3, the ventricle; 4, 5, the large atrium cordis, or auricle; 6, the diaphragm; 7, the aorta descendens; 8, the pneumogastric; 9, its branches; 10, its continuation. (Von Bär.)

As soon as the capillary system is fairly established, the change in the character of the function of nutrition alluded to is accomplished, and in those animals which depend for their development on a food yolk, it is eventually entirely covered with ramifications of these vessels. The blood-cells of the first order or series are evolved from the nuclei of the cells which coalesced for the formation of blood-vessels.

The development of the embryo still continuing, it assumes a form which has been aptly described as resembling that of a boat placed upside down, the bottom of the boat rising higher and higher above the surface of the germinal membrane, and lifting with it that portion of the membrane to which it is attached. The two ends of the boat-shaped body bend under toward one another; the larger of the two is destined to become the head of the embryo. As this elevation takes place, the embryo becomes separated by a constricted space from the surrounding germinal membrane, its abdominal parietes being still open and in contact with the yolk. From the layer which thus lines the interior of the cavity of the embryo, the intestinal canal arises as a tube from the coalescence of a pair of lateral ridges, and the surrounding and exterior portions of the germinal membrane, elevating themselves above the constricted space, coalesce over the back of the embryo, and thus inclose it in a sac. This sac constitutes the amnion, and in this manner, by folding, the interior of the germinal membrane is used as a digestive surface, the outer as one for secretion. The umbilical cord obtains a sheath from the amnion, which at one end is continuous with the skin of the fœtus, and the other is reflected over the surface of the placenta. The amnion therefore constitutes a closed sac, which contains a fluid, the liquor amnii.

Elevation of the embryo.

The amnion.

The place at which the germinal membrane is constricted, so as to be able to act as a digestive surface to the embryo, though linear at first, is gradually narrowed down, and constitutes the umbilicus. This constricted part is now the omphalo-mesenteric duct, which of course communicates with the cavity of the yolk-sac, which, at this stage of devel-

opment in mammalia, is the umbilical vesicle. In birds, the yolk-sac is carried completely into the abdomen through the umbilical opening; in mammals it remains exterior. It does not appear that the contents of the yolk are directly absorbed from the cavity of the sac, but they are carried by the ramifying vessels to the liver. These vessels are therefore counterparts of the mesenteric. Eventually folds arise on the lining membrane of the yolk-sac over which these vessels pass, and which facilitate absorption. In fish, at this stage, the yolk-bag hangs down, and respiration takes place upon its surface.

The allantois.

From the caudal extremity of the embryo the allantois emerges as a mass of cells, of which the interior liquefy, and the exterior then constitute a sac. In birds and in reptiles it reaches considerable development; in the former extending entirely over the yolk-sac, but in mammals it is soon replaced and shrivels up. It discharges the function of a urinary bladder, and, indeed, a portion of it continues to do so in man. Its disappearance is the signal that the embryo is now depending on the placenta.

Development of the circulatory system.

To return now to the development of the circulatory system. At about the end of the eighth week, as we have seen, the ventricle is divided by a septum, the division of the auricle not occurring till a little after, and even then not being perfect, an aperture, the foramen ovale, existing. This is the state of things at about the twelfth week: of the five branchial arches two disappear, the aortic bulb then divides into two tubes, which are to be the aorta and pulmonary artery respectively. Next, one of the branchial arches forms the subclavian and carotid arteries. Of the middle pair, the right is obliterated, but the left remains to constitute the arch of the aorta. Of the lowest pair, the right forms the right and left pulmonary arteries, and the left constitutes the ductus arteriosus.

The fœtal circulation.

The blood-system having reached its full development, the fœtal circulation may be described as follows: From the placenta oxidized blood is brought through the umbilical vein, a part passing into the ascending cava through the ductus venosus, and the rest into the liver through the vena portæ, from which, by the hepatic vein, it also reaches the ascending cava. In its passage to the heart it becomes adulterated with blood derived from the trunk and lower extremities. It next gains into the right auricle, and, to some extent, is kept from contamination with the venous blood coming through the descending cava by means of the Eustachian valve, which directs the arterialized blood through the foramen ovale into the left auricle, from which it gains the left ventricle, and also directs the venous blood of the descending cava into the right ventricle. The blood which is in the left ventricle is driven therefrom into the ascending aorta, and supplies the

head; but the venous blood which is in the right ventricle is driven therefrom through the pulmonary artery and ductus arteriosus into the descending aorta, and, mingling with the arterial blood therein, passes to the trunk and legs. Of this blood a portion is then carried to the placenta to be arterialized.

At the moment of birth a change takes place in the manner of the circulation, which is now arranged upon the type described at page 134. This is accomplished as described at page 148.

From the description which has thus been given, it may be gathered that, up to the period of birth, three distinct types of nutrition have been followed. They may, with sufficient accuracy, be designated, 1st. Yolk nutrition; 2d. Tuft nutrition; 3d. Placental nutrition. To these may be added the two followed at a later period: 4th. Lactation, and, after the dental mechanism is supplied, 5th. The diet of mature life.

Three types of nutrition.

Respecting the development of special organs, it may be remarked that of those which are permanent, the vertebral column is one of the first to appear; it shows itself under the form of isolated quadrangular elements. The gelatinous cellular structure, chorda dorsalis, acquires a sheath, which assumes a fibrous structure, and from this, in the lower vertebrates, the vertebræ are evolved. In man, the elementary quadrangular plates are considered to have an independent origin. As they increase in number and size they surround the chorda, and projections springing from their superior surface form arches to envelop the spinal cord. Each vertebra, therefore, is constructed by the union of two pieces, one on either side. These first assume the condition of cartilage, and, later, the body and arches ossify from separate points. The chorda dorsalis, which has, during this development, been gradually evolved in the bodies of the vertebræ, disappears.

The vertebral column.

The bones of the skull are metamorphosed vertebræ, of which, according to Professor Owen, four appear to have undergone change. To these the auditory, gustative, optic, and olfactory nerves are respectively related, in the same manner that the spinal nerves are to their vertebræ.

In the descriptions given in the preceding part of this work, incidental allusion to a sufficient extent has been made to the development of most of the apparatus of organic and also animal life. It may therefore here be briefly stated that the alimentary canal originates in the pinching off of a part of the blastodermic vesicle below the spinal column. At first it is a straight tube, which communicates about its middle with that vesicle, but after a time shows its eventual division into œsophagus, stomach, large and small intestines, assuming an oblique position on the part to be occupied by the stomach, and then curving in the region of the intestine. From a part of this tube

Development of the apparatus of organic life.

the liver emerges as a thickened deposit of cells, into which the wall of the intestine bulges so as to form a kind of sac, and from this rudiment a ramified structure arises, which at last recedes from its place of origin, and is connected with the intestine by the hepatic duct. The commencement of this structure is about the third week, but it proceeds with so much rapidity that in the third month it nearly fills the abdominal cavity. The functions of the liver at this period have already been pointed out, the meconium it secretes being modified bile (page 202). In like manner, from the digestive tract, the pancreas and salivary glands originate from masses of cells, ducts being formed by deliquescence of portions within. From the alimentary canal, also by budding and deliquescence, the lungs arise, their cavity communicating at first by several apertures with the pharynx. This occurs about the sixth week. These organs are gradually removed from the place of origin, as in the case of the liver.

The Wolffian bodies are temporary urinary organs, which precede the kidneys and eventually disappear. They are of an ovoid shape, and consist of a duct from which transverse canals branch forth, the duct discharging into the sinus urogenitalis. They originate about the end of the first month, and commence to degenerate in the third. In fishes they remain as the permanent urinary apparatus. The testes or ovaries arise from the inner margin of the Wolffian body, the former being guided into the scrotum by the gubernaculum. This descent commences between the fourth and fifth month, and is completed at birth or shortly after.

The Wolffian bodies.

Among the indications that conception has occurred are usually enumerated, stoppage of the menses, the placental murmur, the development of the mammary gland, its sense of pain or tenderness, the color of the areola, the turgescence of the areola and nipple, irritability of the stomach. Quickening, as it is termed, usually occurs about the eighteenth week, and parturition in the fortieth, or at the close of 280 days. With respect to this, it is admitted that the term may be possibly prolonged, in very rare cases, by 40 days. The French laws legitimatize a child born within 300 days; and that such variations of the proper term may occur is proved by observations made upon domestic animals, in which the duration of pregnancy can be ascertained with precision. In the cow, which has the same period of gestation as the human female, the shortest period hitherto observed is 213 days, the longest 336. The shortest period at which human parturition can occur, consistent with the viability of the child, appears to be about 23 weeks.

Indications of conception.

Period of gestation.

The act of parturition in its first stage is to be referred to a contraction of the muscular fibres of the fundus and body of the uterus with a synchronous relaxation of those of the cervix.

Mechanism of parturition.

At a later period the contraction of the expiratory muscles assists. After birth is accomplished, the mouths of the uterine vessels are closed through the contraction of the organ, the lochial discharge carrying with it any disintegrated residues of the deciduous membrane, and also large quantities of fat, derived probably from the degeneration of the uterine structure itself.

Influence of both parents. That both parents are concerned in imparting characteristics to the child there can be no doubt: it is fully established where they are of different races, as white and black, or white and red; and equally in the case of animals, as in mules, produced by the mixture of different kinds. It is scarcely necessary to remark that this extends to the communication of more refined peculiarities, the resemblance of countenance, figure, gesture, and even mental qualities, family likenesses which we daily observe. These impressions are of a much more profound character than might at first be supposed, as is proved by the fact that the third generation will exhibit peculiarities belonging to its progenitors, though those peculiarities have not occurred in the second. Even after parturition is over there still remains impressed upon the female a definite change: this is illustrated by the well-known case of a mare which had borne a colt by a quagga, her subsequent colts by horses being distinctly marked like the first; and in the human female cases are of common occurrence in which the offspring of a widow, who has been married a second time, resemble her first husband. Marriage produces in this respect a permanent change in the female, a constitutional impression not disappearing in any length of time, the influence of the first husband reappearing in the children of a subsequent contract.

2D. GEMMATION.

Gemmation of plants and animals. The ascending axis of a plant is terminated by a differentiating part, surrounded by protecting structures. From this, as growth takes place, leaves or their modifications are produced. This differentiating part is a bud. In like manner may be found in the axils of leaves similar buds, which pass by development into branches, but sooner or later the terminal buds are checked in their longitudinal increase, and the parts to which they would have given origin spirally being compressed into circles, a flower arises, and further development ceases, the reproductive phase being now assumed.

Fig. 265.

Hydra budding.

Among the lower animals propagation by buds is also observed. Thus the hydra exhibits this manner of increase, as seen in *Fig.* 265; and even upon the buds thus produced, other buds, of a second order or generation, are found.

Propagation through the agency of buds is termed gemmation. It may be accomplished either by the natural or artificial separation of the buds from the parent stock. Thus, in the hydra, the buds may spontaneously be separated from the parent, and thereby give rise to free individuals, or they may be purposely cut off with the same result. In the case of plants, artificial separation is constantly resorted to, as in the various methods of budding and grafting employed by horticulturists for obtaining the finer varieties of flowers or fruits. It consists essentially in placing a bud of the plant which it is desired to propagate upon a stock of a different kind, in such a way that, as development of the bud or scion takes place, union or incorporation with the stock shall occur. There are many different ways in which grafting may be performed; they all depend for their success, however, upon causing the alburnum of the scion to coincide with that of the stock, so that the vessels of the former may receive the sap arising from those of the latter. When the parts are thus adjusted, they are to be retained in their position by bandages or other suitable means, and protected from the air and rain by means of clay or wax. The most suitable time for this operation is in the spring, just previous to the rising of the sap.

Methods of grafting.

There are certain limits within which the operation of grafting must be performed. The stock and the scion must be nearly related to each other. If species of different natural orders be grafted they will not take, but the species of the same genus may.

Limits of gemmation.

If in this manner we take a bud, and graft it on a stock of an allied kind, it will continue to grow and develop in the same manner that it might have done without detachment from the parent plant, and in the same manner from the new plant that has thus arisen, by a repetition of the process, plant after plant, for many generations, can be secured. Experience has taught us that, whatever might have been the peculiarities of the original from which the first bud was taken, those peculiarities, whether of odor, taste, color, or shape, will reappear in the product; but experience has also taught us that there is a limit beyond which these repetitions can not be conducted. The valued fruits and flowers of the old times have thus disappeared. Propagation by gemmation is therefore considered as tending to exhaust the original plastic power. But it is to be remarked that, if from these artificial growths seeds be taken and caused to germinate, the plants so arising no longer present the special, and, perhaps, valued peculiarity, but in many instances run back at once to the original and wild stock.

Nature of propagation by gemmation.

We are apt to attach to propagation by gemmation more importance than it really deserves in a philosophical point of view when it thus appears to have given rise to new and successive generations of individuals. But, after all, wherein does it differ essentially from what goes on natur-

ally? The manner of extension of any given plant is by bud after bud in succession, either terminal or axillary; but this extension does not go on indefinitely; it reaches a limit both as respects size and duration. We never notice in the development of a bud which remains attached to its parent stock the spontaneous appearance of novel qualities. The flowers and fruits are like all the others upon the same plant. If such a bud, then, removed from its parent seat, be permitted, under favorable conditions, to grow elsewhere, it might be expected, as is actually the case, that it would go on in its development without exhibiting any alterations.

Essentially of an exhausting nature, reproduction by gemmation is limited. It can only be repeated a definite number of times. At the most, all that we do in this artificial process is to obtain a part of an old individual under a new and isolated form. We thereby relieve such new growth from the chance of those accidents which may befall the original stock; but both for the one and for the other there is a definite term of life. When that term is approached, though we may take scions or buds, and treat them with every care in the usual operation of grafting or budding, the operation will fail.

There is a certain analogy between this incorporation of the parts of different plants and the so-called grafting or Taliacotian operations which are sometimes performed on the parts of animals, as the transplantation of the spur of one bird on the top of the comb of another, or many of the plastic operations of surgery; but these parts do not necessarily perish in the manner which has been indicated by Butler in his Hudibras.

Propagation by gemmation and reproduction by generation are, in many instances in the animal series, resorted to alternately for the continuation of the race. Thus, during the summer season, propagation by gemmation may serve to increase the number of a given kind, but if these should be unable to maintain themselves during the cold of winter, the race would inevitably become extinct, unless reproduction by ova were resorted to; for though the developed animal may not be able to withstand the decline of temperature, the ova may. Thus, in a hydra, propagation by gemmation continues until the external temperature lowers to a certain degree, and that at once brings on a reversion to the other process. The same thing has been observed in the case of the aphis, which multiplies by gemmation until there is a reduction of temperature, and then it multiplies by generation. We have already dwelt at length on the control which external circumstances have over development; it is, therefore, no more than might be expected that they should, in like manner, determine the processes of propagation and reproduction.

Influence of temperature on spontaneous gemmation.

Gemmation occurs only in a very doubtful way and under special circumstances among the more advanced members of the animal series. In

man, there is reason to suppose that gemmation can only take place in the earliest periods of existence, perhaps at the epoch of the formation of the mulberry mass. Upon this principle an explanation of the occurrence of double monsters has been given.

3D. ALTERNATION OF GENERATIONS.

It has been already explained that by this phrase is meant that a parent plant or animal will give origin to a form wholly unlike itself, and this form, perhaps after the lapse of years, will give origin to another unlike itself, but similar to the original progenitor. Thus the Salpæ present themselves under two different aspects, the solitary and the aggregated, the latter being produced from the former by being budded off in an internal stolon, the individuals being united to one another in an aggregation or chain after they have been separated from the parent. These aggregated salpæ alone have sexual organs and produce ova. From each ovum a solitary salpa arises, which repeats the process described again. The solitary salpa, therefore, multiplies by gemmation, the aggregate by generation. Nor is this process confined to animals; it is also observed in the case of plants. Thus, in ferns, the spore produces the prothallium, which becomes a distinct organism, separated from its parent, and carrying on its nutritive processes independently for itself. From it arises by generation a fern like the original, which, like it, by gemmation, produces prothallia, but never directly produces a fern. Therefore between each fern and its descendant a prothallium intervenes, the prothallium arising by gemmation from the fern, and a fern arising by generation from the prothallium.

Alternate gemmation and generation.

After a careful examination of Steenstrup's doctrine of alternations of generation, Dr. Carpenter concludes that it can not be received in the form originally presented, since we should regard a generation as embracing the entire product from generative act to act. Indeed, the intermediate forms are often nothing more than sexual organs, furnished or not with an apparatus of locomotion, or, in the more complicated cases, having a mechanism of nutrition attached sufficient for their purpose. The correctness of this interpretation may be illustrated by such cases as the development of medusa buds, which, being first attached to the parent, gradually exhibit the formation of an independent digestive apparatus, and when this has reached a certain degree of perfection, they are separated and swim off, generative organs then arising in these buds by which true ova are formed. In the Sentularidæ buds are developed in ovarian capsules, and these reproduce in their turn ova by generation. The rate at which gemmation goes on in many of these instances is obviously connected with physical conditions, more particularly the degree of temperature and the supply of food.

Explanation of alternations of generation.

The fact of the apparent dissimilarity between the product of gemmation and the product of generation ceases to have any force as soon as we consider the former in the attitude which it really ought to occupy, as not constituting a distinct individual, but merely a part, a derivative, or an appendix of the product of generation; and this view of Dr. Carpenter's seems, therefore, to be the proper interpretation of the whole case.

CHAPTER V.

THE GROWTH OF MAN.

Infancy.—Weight and Size of the Infant.—Weight and Size at subsequent Periods.—Development of the Intellect.—Maturity of Man.—Tendency to Crime.—Maxima of Physical and Mental Strength.

Mental and Physical Decline.—Mortality at different Periods of Life.—Comparative Structure, Functions, and Mortality of the two Sexes.

Artificial Epochs of Life.—Gradual Change in the Mental Qualities.—Independent Existence of the Soul.

In the last chapter the successive stages of embryonic development were described. It was shown that at one period nutrition is solely at the expense of the yolk of the ovum, which is appropriated by a simple surface-imbibition; and that this, in due time, is succeeded by what has been designated tuft nutrition. At a later period, this mode, in its turn, is replaced by another, depending on a vascular arrangement, the placenta. For a considerable period after birth a fourth system is relied on, nourishment by milk; and it is only by degrees, when the necessary changes have been made in the digestive mechanism, the teeth being cut, that the final mode of nutrition is assumed. Even after this the human infant leads a dependent life, because of its own weakness and imbecility, irrespectively of any peculiarities of our social state. So far, therefore, from man not exhibiting those metamorphoses which are undergone by the lower members of the animal series, he of all displays them in the most marked way, for they do not cease at the period of birth, but reach through many subsequent years—a gradual development of the body, attended by a gradual change in the manifestations of the mind.

Infancy of man.

At birth, the human infant is the very representative of weakness and imbecility. Though, unlike many other mammals, it opens its eyes at once, it exhibits no token of visual perceptions; though it may be subjected to sounds or noises of various kinds, it takes no notice whatever of them. This condition of inertness is followed by a condition of confused sensation, which by degrees is succeeded by a capability of ap-

preciating special ideas. Buffon has very truly said that the earliest period of conscious existence is a scene of pain, the life of the infant being divided between sleep and crying; from its slumbers it is awakened only by the pains of hunger; nor is it until after the lapse of many days, or even weeks, that the first smile is seen. It is too feeble to turn from side to side, but remains in the position in which it was placed. Its skin, which at birth was covered over with a whitish incrustation, the vernix caseosa, becomes reddish, the depth of this tint, however, shortly passing away. At this period, moreover, life is purely vegetative, the infant feeding and sleeping. The biliary matter, meconium, which had accumulated in its intestine during fœtal life, is discharged in the course of a day or so after birth, and the digestive apparatus enters on its functions with activity.

It is said that the infant smiles soon after it is forty days old; though it can cry it can not shed tears. Before long it gives indications of its satisfactions and dislikes. The power of moving in an erect posture is gained by it in the course of a year, and by the close of that time it can masticate. Of its teeth, the central incisors appear about the seventh month, those of the lower jaw first; the lateral incisors about the eight or tenth, the anterior molars about the twelfth, and the canines about the eighteenth, the posterior molars being cut between that time and three years. The average date of the appearance of the permanent teeth is, the front molars about the seventh year; middle incisors, eighth; lateral incisors, ninth; anterior bicuspids, tenth; second bicuspids, eleventh; canines, twelfth to thirteenth; second molars, twelfth to fourteenth; and the last molars from the seventeenth to the twenty-first year.

The teeth.

The power of articulate speech is displayed within twelve or fifteen months, some letters being more easily gained than others; among them are A, B, P, M.

Speech.

From henceforth the mind emerges with rapidity from the confusion of a multitude of impressions, and learns to concentrate itself at pleasure upon one. This capability of mental abstraction is a process of specialization, and is a manifestation of the law of Von Bär. The intellectual difference which we eventually observe between one man and another is, to no inconsiderable degree, dependent upon such an ability of concentrating thought. He who conceives of a thing distinctly is very likely to express himself of it clearly.

Concentration of the attention.

Throughout infancy and childhood, the features, and even the gestures, indicate the profound constitutional changes which are going on. The countenance, instead of expressing pleasure and pain in the aggregate by smiling or crying, as was the case at first, gains the faculty of representing every grade of feeling. Long before maturity is reached we read without difficulty the thoughts which are passing in the mind from the

movements of the lip or the eye, and the painter can express every shade of feeling, and every emotion, by the mere configuration of the outward form.

Mean length of the infant.

The monthly growth of the fœtus for six months before birth is established at two inches. At birth, the mean length of boys is $18\frac{1}{2}$ inches, and of girls $18\frac{1}{8}$ inches, the former being therefore a little the longer.

Growth of boys and girls.

At sixteen or seventeen years the growth of girls is relatively as much advanced as that of youths of eighteen or nineteen. For the most part, the inhabitants of towns are taller than those of the country. The full height is not reached, in some instances, until twenty-five years; in very warm and very cold climates it is more quickly attained. The recumbent position is regarded as being favorable to growth, and, influenced by his own weight, an individual is shorter in the evening than when he first rises from bed in the morning.

With regard to the rate of growth, it may be observed that it is most rapid immediately after birth, and continually diminishes until about five years, the epoch of maximum of probable life. It then remains equable to about sixteen years, the annual growth being $2\frac{1}{5}$ inches. After puberty it declines, being, from sixteen to seventeen years, $1\frac{1}{2}$ inches, and during the next two 1 inch only. The annual increment relatively to the height then attained continually diminishes from birth. The fœtus grows as much in length in a month as the child from 6 to 16 years does in a year. The limits of growth of the two sexes are unequal, because women are smaller than men, terminate their growth sooner, and annually grow less. Individuals in affluent circumstances may often surpass the standard height, but misery and fatigue are liable to produce the opposite effect. Longevity is generally less for persons of great height.

Maximum and minimum height of man.

As to the maximum and minimum of height, it may be remarked that Frederick the Great had a Swedish body-guard whose height was eight feet three inches; and, on the other hand, Birch states that there was an individual, 37 years old, whose height was sixteen inches. In view of these and other such facts, Quetelet fixes on 8 feet 3 inches as the maximum, and 1 foot 5 inches as the minimum of height; he gives as the mean 5 feet 4 inches. Half the men of France, at the age of conscription, are between 5 feet 2 inches and 5 feet 6 inches, but the wars incident on the great Revolution made a permanent impression on the French in this respect by lowering the standard through the consumption of the taller men. M. Quetelet moreover remarks, that in ten millions of men there is but one more than 6 feet 8 inches, and one less than 4 feet. There is reason, however, to believe that this statement will not hold good of America.

Weight of infants. As regards weight, new-born boys are heavier than girls. An average taken from 20,000 gives 6¼ lbs. as the weight at birth; the maxima and minima have been 10½ lbs. and 2¼ lbs. For about a week after birth the weight diminishes, owing to the effect of aerial respiration. The difference in weight between the two sexes gradually diminishes until about the twelfth year, when an equality is reached.

Weight at different periods of life. The maximum weight is attained about 40, and as 60 is approached a diminution is perceived, which reaches 12 lbs. at about 80 years, the stature likewise correspondingly diminishing by about 2¾ inches; the female reaches her maximum weight somewhat later, at about 50 years. The extreme limits of weight in men are 108 lbs. and 216 lbs.; in women, 87½ lbs. and 206½ lbs. The mean weight at nineteen is nearly that of old age in both sexes. At full development the male and female weigh almost exactly 20 times as much as at birth. In the first year the infant of both sexes triples its weight. It requires six years more to double that, and thirteen to quadruple it. Immediately after puberty both sexes have half their ultimate weight. Between the ages of 25 and 40 the mean weight of the male is 136½ lbs., and of the female 120¾ lbs.

Relation of height and weight. With respect to the relation between weight and height, if man increased equally in all his dimensions, the weight would be as the cube of the height; but since this is not so, development taking place unequally, the proportion is not observed, and it is found that from the end of the first year to puberty the weights are as the squares of the heights. M. Quetelet gives as an approximate rule that during development the squares of the weights at different ages are as the fifth power of the heights, the transverse growth being less than the growth in height. The mean weight of a male, without reference to age, is 103¾ lbs.; of a female, 93¾. A similar calculation for the population of the United States as that which has been given by this philosopher for Brussels would give for the total weight of all Americans two thousand six hundred and thirteen millions of pounds.

The weight of an individual, considered without reference to age or sex, is 98¾ lbs.

Maternal love of two kinds. From birth until puberty the mode of life is essentially vegetative, all the instincts having relation to the individual and corporeal development. Except through the intervention of education, the desires of the child are chiefly directed to the pleasures of mere vegetative existence, eating and drinking; and this, in savage races, is witnessed in a much more marked manner than in those that are civilized, in whom the manner of life is affected through the intervention of parental care. In this particular it may be remarked that maternal love is divisible into an instinctive and a moral affection, the former of a lower and

more animal kind, the latter of a higher and intellectual; the former limited to the period of infantile helplessness and dependence, and succeeded by the latter as maturer years are attained. In savage races, however, instinctive affection seems alone to exist, and the intensity of moral affection is, to a certain extent, a measure of civilization. Throughout the first fifteen years of life, with the gradual development of the body there is also a steady intellectual progress, the gains of which seem to be greatest at the earlier periods, and less and less marked as maturity is approached. When we recall the wonderful advance accomplished in the first years, embracing the acquisition of speech, and a knowledge of the nature and qualities of a thousand surrounding objects, we might be led to suppose that our mental acquisitions decline with the progress of life; but this is altogether deceptive; for, though the acquirements of later years be less obvious, they are none the less important and none the less profound.

Character of the life of children.

Through the successive changes to which allusion has now been made, each of which is a strict metamorphosis, and each of which, with its special structures, has its special functions, man at last reaches maturity. In some cases, as we have seen, the stature continues increasing until after the twenty-fifth year, and throughout the whole mature period, even after what has been termed the meridian of life is gained, the weight also becomes greater. This increase of weight, however, has not so much a relation to the muscular as to the respiratory system, for the former reaches its perfection at a much earlier date, the increasing development of the middle period of life being due to a continued tendency to the accumulation of fat. At this period, moreover, the object of life has undergone an entire change; the vegetative propensity, or that for the exclusive development of the individual, has declined in prominence, and the reproductive has been assumed. With this there have been awakened new sentiments and new emotions, affording still another corroborative proof of the connection of mental habitudes and structural condition. The psychical powers are now advancing toward maturity, an advance which they continue to make until about the fiftieth year. Throughout this whole period, and even at this extreme date, we still notice how much intellectual capacity is connected with the perfection of corporeal development. It needs but a little experience for us to determine at a glance the intelligent from the obtuse, and to read even the minor shades of character in the aspect of the face. Without being aware of it, we are constantly putting into requisition the principles of phrenology and physiognomy, and drawing conclusions respecting character to a certain degree correct, from the expression of the eyes, the lineaments of the countenance, or the configuration of the head.

The maturity of man.

The actions of man are closely connected with the physical and moral

circumstances under which he is placed. The greatest number of crimes against persons and property is among the inhabitants of river-banks. The period of the maximum of crimes against persons coincides with that which is the minimum against property, and is the summer season. As respects each individual, his tendency to crime is at first against property, and this reaches its maximum at about 25 years of age, whereas the tendency to crime against persons commences later than that against property, and increases with the increase of strength. In crime, man, as he grows older, substitutes stratagem for force. If brought up in a liberal profession, his tendency in crime is against persons, but that of the workman is against property. Elementary instruction, so far as reading and writing go, does not lead to the diminution, but rather to the increase of crime: a very important conclusion, more particularly in the United States, in many portions of which this kind of education is chiefly patronized by government, to the exclusion, to a certain extent, of that which is of a higher grade, and which serves to correct this important defect. Moreover, superficial education makes the mind a ready receptacle for every kind of imposture, and has been the cause of the rapid spread of many modern delusions, such as spiritualism and homœopathy.

The tendency to crime in man.

Prejudicial effect of low education.

As regards women, their tendency to crime, when compared with that of men, is as 23 to 100; at least this is the case in France. Their tendency for the perpetration of crimes against persons is less than that for crimes against property in the proportion of 16 to 26. It is interesting to observe that the physical force of woman, as compared with that of man, is also as 16 to 26. From such considerations, it may therefore, perhaps, be concluded that the morality of women is about the same as that of men, their physical feebleness and modesty being taken into account. In woman, the maximum tendency for crime occurs at about 30 years, but then she relinquishes that disposition sooner than man. Her tendency to theft, however, begins early, and lasts through life. When she desires to commit murder, she employs, by preference, poison. In this may be discerned the influence of her constitutional element, physical feebleness. Timid at explosions and at the sight of blood, if driven to the extremity of self-destruction, she instinctively resorts to drowning. Women, like men, who are the residents of towns, are much less moral than those who live in the country. This may be inferred from such facts as that the annual percentage of still-births occurring in the former is very near double of that occurring in the latter case; and though this may be, to a certain extent, connected with the fashionable restraints of clothing and social dissipations, it is far more due to female depravity. The illegitimate births of towns compared with those of the country are as 23 to 7. Among the still-

The tendency to crime in women.

born, the illegitimates are to the legitimates as 5 to 3. In the city of Berlin, the illegitimate still-births are to the legitimate in as high a proportion as 3 to 1.

The passions of man are gratified in a manner that seems to be independent of religious profession. The open dissoluteness of one country is counterpoised by the secret crime of another. Protestant England and Catholic France exhibit a striking illustration. In the former, in 1845, the number of illegitimates was 70 per thousand of the whole number of children born. In France it was about 71.

Succession of psychical persuasions.

During the process of the development of the intellect of man, various psychical persuasions in succession arise, which are frequently imputed to education or tradition, but of which the origin is undoubtedly to be traced to the organization. Those general ideas that are found all over the world, among all races of mankind, whatever may be the climate in which they live, their social condition, or religious opinions—ideas of what is good and evil, of virtue, of the efficacy of penance and of prayer, of rewards and punishments, and of another world: these, from the uniformity of their existence in all ages and in all places, must be imputed to the stamp that has been put upon our cerebral organization. In the same light we must view, as Dr. Prichard has said, the delusions and fictions which are universal, such as ghosts and genii, giants and pigmies. Universal opinions are not the result of accident, nor always of tradition. They are often creations of the mind, arising from peculiarities of its constitution.

Successive maxima of physical and mental strength.

Arrived at maturity, the system of man commences at once to decline, the epochs of the maximum of physical and mental strength not, however, coinciding; that for the former occurring at about the 25th year, as previously remarked, but that for the latter not until between the 45th and 50th year. At this period, when the powers of imagination and reason have reached their highest degree, the liability to mental alienation and insanity is also at its maximum.

Order of mental and physical decline.

Somewhat later, the physical system plainly betrays that it is pursuing its downward course, retracing the steps through which it passed forward to development. Soon there is an evident decrease of weight, the nutritive operations being no longer able to repair the waste of the body. There is also a diminution of the height. This corporeal decay is the signal for a depression of the mental powers, the first which begins to yield being probably that of concentrating or abstracting the thought. As years pass on, external impressions exert a diminished influence, and he who at an earlier period reached the meaning of things, as it were, almost by intuition, now casts his eyes over page after page without an idea being communicated to his mind. The old man querulously complains that he reads his book, but

does not understand what it means. With this failure of perception the powers of memory decline, recent events fading away first, but those of early life being recollected last. The present no longer possesses an interest, for the brain is less capable of receiving any new impressions. One after another, the organs of sense fail to discharge their functions; the sight becomes misty, the hearing dull; there is an indisposition for exertion, a desire for repose. The white-bearded patriarch of a hundred years sits quietly by the fireside, resting his hands on the top of his staff.

Extreme old age.

Instances of Longevity.

	Years.
Attila	124
Margaret Patten	137
The Countess of Desmond	145
Thomas Parr	152
Thomas Damme	154
John Rovin }	172
His wife }	164
Peter Torton	185

The mortality of towns is greater than that of the country. As we advance from the midst of the temperate region toward the equator or toward the poles, it also increases: thus, in the northern portions of Europe, the annual mortality is as 1 to 41; that of Central Europe, 1 to $40\frac{8}{10}$; that of Southern Europe, 1 to $33\frac{7}{10}$. Considered as respects different periods of life, the rate of mortality varies very much. Of both sexes, 22 per cent. die before they are one year old, and 37 per cent. before they are five years old. Male infants are, however, more liable to die immediately after birth than female, but at the close of about two years their mortality is the same. Nine twentieths of the whole number born die before they are fifteen years of age, that is, before they have become useful to the community.

Local mortality.

Mortality at different periods of life.

The mortality among girls increases between 14 and 18, and among men between 21 and 26. In France and Belgium, from 26 to 30 is the epoch of marriage, and at this period the mortality is the same in both sexes. It then increases for the women during the years of childbearing, and afterward again becomes equal for both. At 25 years half the births are dead. The mean life may be estimated at 33 years. The maximum expectancy of life is at 5 years, at which age the risk of mortality is suddenly reduced, and becomes small till puberty, when, especially among girls, it becomes great. From 60 to 65 the chances of life are again at a minimum.

Relative mortality of the sexes.

To the foregoing statements, in which contrasts have been drawn between the male and female, the following may be added: Not only is there a difference in the entire stature, but the different portions of the

Comparison of the structure of the male and female.

body have not the same relative size. The capacity of the skull in the female is less; the body is longer; the lower extremities shorter; the pelvis of greater size, especially in its transverse diameter; the heads of the thigh bones, therefore, farther apart, and the bones themselves including a larger angle than in the case of the male; the chest and the abdomen are respectively more convex; the transverse diameter at the shoulders smaller, and the upper extremities, like the lower, shorter; the hands and feet, fingers and toes, of less size. The surface presents a more elegantly rounded form, without angularities; the skin thinner and more translucent; the hair of the head is longer and finer, but other portions of the skin less covered with hair; the nails smaller and thinner.

Functional peculiarities of the female.

The strength of the female is to that of the male as 16 to 26. Her muscles contract with less energy, and are more easily wearied. The peculiarities of the construction of the bones of her pelvis and chest respectively give rise to peculiarities in the movements of the lower and upper extremities; hence the characteristic manner of walking and movement of the arm in attempting to throw a stone. In the chapter on the voice we have already pointed out the female peculiarities in speaking and singing, and its more acute quality.

Her moral and intellectual peculiarities.

With respect to her moral and intellectual peculiarities, these are manifested from the earliest infancy in the sports and games which she instinctively follows. Coming to maturity more rapidly than the male, she abandons these, though they may still be enjoyed by boys of her own age, whom, for the course of a year or two, she regards with neglect or even disrespect, a feeling soon after to be followed by timidity. Education and the position in which she may have been placed may, to a certain extent, control or disguise her habits, but they can never wholly obliterate the striking predominance of her moral over her intellectual qualities, as compared with man. Essentially religious, her faith is applied to almost all the ordinary affairs of life, though when she finds that she has been deceived she is ever distrustful. From the earliest times it has been remarked that her revenge, more particularly when it concerns wounded pride, is implacable. Much more than the male she is delighted with the adornments of dress. Her reasoning powers are less vigorous, though her sensations are more acute, yet she bears pain with more resignation than man. Her judgment is not so evenly balanced, and is often perverted by the preponderance of her feelings. It has been asserted that these moral and intellectual peculiarities which she presents when compared with man are distinctly traceable to the phrenological predominance of the moral over the intellectual regions of the brain.

The physiologist who is thus obliged to speak of the constitutional

and mental imperfections of the female, may be permitted to turn with delight from the dry details of statistics and anatomy to the family and social relations, for it is therein that her beautiful qualities shine forth. At the close of a long life, checkered with pleasures and misfortunes, how often does the aged man with emotion confess that, though all the ephemeral acquaintances and attachments of his career have ended in disappointment and alienation, the wife of his youth is still his friend. In a world from which every thing else seems to be passing away, her affection alone is unchanged; true to him in sickness as in health, in misfortune as in prosperity, true in the hour of death. When the schemes that occupied his active years have vanished, or, if realized, are now no more to him than vanities which hardly fasten his thoughts; when, in the feeble extremity of age, every thing is a burden to him, and the passing excitements of others can not even arouse his attention, the echo of those prayers is still heard which his unskillful tongue first learned at his mother's knee. The stern, the avaricious, the hard-hearted, the intellectual, all are equally brought to confess who was their first and who is their last true friend.

Artificial epochs of life.

The necessities of society have led to the establishment of artificial epochs in the life of man. In most countries, the first recognized movements of the fœtus are taken as the period from which independent life begins, and the twenty-first year is fixed as the time of maturity. These arbitrary dates answer the purpose very well, but they have not that physiological significance which is commonly supposed, for neither of them coincides with any great change in the mode of life. Of the metamorphoses through which we pass, the final one, occurring at puberty, which separates the merely vegetative from the reproductive period of life, is, under the circumstances of the case, with the exception of the assumption of aerial respiration at birth, the only obvious one. The change which then ensues is in no respect less marked than the passage to the perfect or imago state by insects. Development suddenly takes on a new phase, and with the physical change correspondingly occur changes in the psychical endowments—modesty and womanly sentiments in the one sex, courage, the perception of honor, and manly qualities in the other, the capability of mutual love in both. Even among animals under the same conditions, analogous results are presented, though in a less refined way.

Encroachment of the vegetative period of life.

The human species is no exception to the observation long ago made, that the undue extension of the vegetative period of life into the reproductive is at the expense of the latter. In the same manner that a tree overladen with foliage presents its flowers scantily, so a love for the pleasures of the table and a predominating epicurean turn is often the indication of incapability.

Up to the fourteenth year, the human being lives solely for itself; its instincts are for the gratification of its present wants, and those wants are, for the most part, connected with its vegetative development. After that period its life is for the future, and is in relation to the race. With this more elevated condition, new emotions and passions have been awakened; there is a gradual unfolding of the mental powers, and a balancing arising from increased knowledge and increased experience; yet, even now, the mental qualities that are most marked are only the extension of those the germ of which may be discovered at the first dawn of reason, and the same may be said even of our intellectual impressions. The ideas we have gathered as members of a family are reproduced and expanded in our religious views, and the government of GOD is presented to the human heart less acceptably when he is set forth as the Almighty Maker of the world than as the Universal Father and Giver of all good.

Gradual change in the mental qualities.

In a preceding chapter I have already shown how the existence of the immaterial spirit of man may be investigated physiologically. It may not be out of place here to dispose of an argument that some have insisted on, that, since the development of the mind proceeds in an equal step with the development of the body, each expanding or declining with the other, the dissolution of the animal fabric is the token of the death of the soul. Against this doctrine the whole human family, in all ages, has borne its testimony, and, if universal impressions arise from physical constitution far more than they do from tradition, it may be truly said that that doctrine is incompatible with the organization of man. Probably there is no question which has received a greater amount of individual and general attention—none which has more deeply exercised the thought of the profoundest intellect; and what is the actual result? Whatever may be the social state, barbarous or polished, whatever the manner of life, whatever the climate, whatever the form of religion, the assertion of the existence of the spirit after death is so universal, that it may be termed one of the organic dogmas of our race. Indeed, we may affirm that the mind has to be educated, trained, or strained before it becomes capable of an opposite view, which, even then, will be doubtingly entertained.

Parallel of corporeal and mental development.

If there is a point in natural philosophy which may be regarded as finally settled, it is the imperishability of the chemical elements and the everlasting duration of force. With the system of nature existing as it is, we can not admit that an atom of any kind can ever be destroyed; and a like assertion may be made of force. Heat may give rise to motion, motion to electricity, electricity to heat: one kind of force may be converted into another, there being a perfect correlation or quality of substitution among them. The quan-

Independent existence of the soul.

tity of power is now the same as it ever was. Its variations are analogous to the apparent transmutations of ponderable material. They are mere metamorphoses.

Matter and force are equally incapable of destruction. Each constituent atom of the animal mechanism, though it may be dismissed for the time as useless, is not lost, but sooner or later is economized in some organic form again. The heat which seems to arise from the most insignificant muscular contraction has been, so to speak, many a time in existence before, and after it has escaped from the system is not lost to the world, but discharges one function after another forever; and if thus neither matter nor force can die, it would be a great anomaly if the principle of conscious identity were capable of annihilation. Like them, it may be capable of modification or change, and, like them, it is not capable of loss of existence. The creeds of various nations recognize this great truth; they differ only in their ideas of what that future state of modification may be.

Perhaps in some age hereafter physiology will find herself sufficiently advanced to offer her opinion on this profound topic, for I can not think that God has left us without a witness in this matter, even in the structure and development of the body itself. From the moment that we see the first traces of the nervous mechanism lying in the primitive groove, we recognize the subordination of every other part to that mechanism. For it, and because of it, are introduced the digestive, the circulatory, the secretory, the respiratory apparatus. They are merely its ministers. And, fastening our attention on the course which it pursues, we see that it is at once a course of concentration and development. The special is at each instant coming out of the more general, and, from the beginning to the end, the whole aim is at psychical development. The germinal membrane is cast away as soon as a stomach can be prepared, aquatic respiration ceases as soon as aerial can be maintained. The scaffolding that was of use at one moment is thrown aside as soon as a new elevation is reached. The germ, the embryo, the infant, are only successive points in a progress which at every instant displays this casting away of the means that have been used as soon as they are done with. That is the style in which the work is carried on. The principle which obscurely animated the germ is the same which in a higher way animates the embryo, and this again is the same which, in a more exalted condition, animates the infant and the man. The cloudy speck which ushers in the phantasmagoria of life expands as the great Artist directs until every lineament has become visible.

That active agent which was first laid in a fold of the germinal membrane was not annihilated when its type of life was changed to placental and therefore aquatic respiration. It withstood the shock when again,

after a due season, it was suddenly madè to breathe the air. Arrived at the mature condition, there is not in its companion-body a single particle that was present at birth. All has changed. And, what is still more important, not only has there been this interstitial removal, but, in succession, the very nature of every one of its organs has changed. It is needless now to repeat how many different systems of nutrition it has depended on—how many sorts of stomachs in succession it has had—how it has breathed by a membrane, by gills, and by lungs—how it has carried on its circulation without a heart, with a heart of one cavity, and finally with one of four. Through all these losses and changes the immaterial principle has passed unscathed, and even gathering strength. In the broadest manner that a fact can be set forth, we see herein the complete subordination of structure and the enduring character of spirit. Whatever may be the mechanism that is wanted, it is in readiness for its time; and when it has finished its duty, is neglected and disappears. There is, therefore, a sound reason in the conclusion to which mankind, perhaps from a mere instinctive impression, have come, that the soul will exist after death, for, after surviving so many mutations, the removal of so many of what seemed to be its firm and essential supports, we are justified in expecting that it will bear without ruin the entire withdrawal of the whole scaffolding.

As I have pointed out, we have precisely the same reason for believing the existence of the immortal spirit that we have for knowing that there is an external world. The two facts are of the same order. Of the future continuance of that external world, irrespective of ourselves, we entertain no doubt; indeed, in certain cases, as in those presented by astronomy, we are able to tell its state a thousand years hence. So long as our attention was confined to statical physiology, every thing connected with the subject now under consideration was enveloped in darkness, but it will be very different when dynamical physiology begins to be cultivated — dynamical physiology, which speaks of the course of life, of organs, individuals, and races. The law of development will guide us to an interpretation of many things which are now shrouded in obscurity, and teach us, from a consideration of what we have learned of our past, and what we know of our present, what we may expect of our future state; and then it will appear that the universal opinion of the ages and nations is not a vulgar illusion, but a solemn philosophical fact.

So, therefore, the decline of the mental faculties with advancing years is no indication of the hebetude of the spirit, or premonitory to its final dissolution. It is only the gradual wearing out of the instrument, the intervention of which has established relations with the outer world. When a tool becomes blunted and old, the workman can no longer manifest his former skill; but the skill may nevertheless remain. Though

the apparatus for the reception of external impressions, as well as that for voluntary action, may be failing, it implies nothing as regards the prime mover. The eye may be dim, the ear dull, and touch imperfect, the voice may be feeble, and the limbs trembling, but all this indicates nothing more than that what has been passed through so often before is about to be passed through again. The organs that have done their duty are to be cast away, but the result of their action is to remain.

It may not, perhaps, fall within the proper compass of a treatise on physiology to speak of that future condition, and yet so deeply interesting are these subjects to all men that a single observation may in this place be excused. The whole course of life, from its very beginning, has been one of development and concentration. We comprehend this the more perfectly as we extend our views beyond our present state, and examine what we have in succession been, and in what manner our existing condition was reached. It is not credible that that system is to be all at once abandoned, or replaced by a contradictory one. Such is not the style in which the affairs of the organic world are at any time carried on. The slowly emerging consequences of the primitive law come forth one after the other in their proper and unvarying sequence, and the law holds on inexorably forever. And since we may say that, throughout those prior states, the idea aimed at is the isolation of a conscious intelligence, every organ being shaped and every function bent to that end, we are reasonably led to the expectation that in a future state that archetype will be completely reached. It would be strange indeed if a blank oblivion should crown such a work.

The future state.

CHAPTER VI.

OF SLEEP AND DEATH.

Causes of the Necessity for Sleep.—Its Duration and Manner of Approach.—Manner of Awaking.—Cause of Night-sleep.—Increased Warmth required.—Connection of Sleep and Food. Of Dreams: their Origin and Phenomena.—Somnambulism.—Nightmare. Of Death.—Old Age.—Internal Causes of Decline.—Death by Accident and by Old Age.—The Hippocratic Face.—Final Insensibility.

1st. OF SLEEP.

One third of the life of man is spent in sleep, a condition of modified sensibility, in which the mind performs its functions in an imperfect way, and voluntary motion is nearly suspended. This state, occupying so large a portion of the short period of time allotted to us, is therefore well deserving of the consideration of the physiologist,

Of sleep.

and the more so since it presents, in the various phenomena of dreams, significant illustrations of the manner of action of the nervous system.

All animals sleep. Many, perhaps most, dream. The necessity for a season of repose arises from the preponderance of the waste of the system over its repair during our waking hours. By bringing the animal functions into a condition of rest, an opportunity is afforded for renovation, and the equilibrium can be maintained.

Causes of the necessity for sleep.

In early infancy, when it is necessary for the nutritive operations to be carried forward with the utmost vigor, and attended with as little waste as possible, the whole time is spent in sleeping and eating. The waking period is gradually increased as the child advances, but not so as to make it continuous, for the day is broken into intervals of sleep. Even at three or four years of age we sleep more than once a day. In mature life eight hours are on an average required, but the precise time varies with different individuals, and even with the same individual in different constitutional states. The time is not, however, always a true measure of the amount of rest, for sleep varies very much in the degree of its completeness or intensity; there is a slumber so disturbed that we are unrefreshed by it, and a sleep so profound that we awake weary. Old age, as it advances, admonishes us to spare the system as much as we may, for repair is conducted with difficulty; and this period, characterized by its resemblance in so many respects to childhood, like it, is often marked by frequently-recurring and prolonged slumber. Moreover, various accidental and other circumstances are liable at all times to disturb its proper periodicity—a warm afternoon, a hearty dinner, an ill-ventilated apartment, monotonous sounds, the attention devoted to one object, bodily quiescence, ceasing to think, the use of narcotics, extreme cold, a horizontal position, &c.

Duration and depth of sleep.

Approach of sleep.

Sleep is commonly preceded by a sense of drowsiness of more or less intensity, which is gradually followed by a loss of sensibility. Objects cease to make an impression on the eyes, the lids become heavy and close. If we are not in the horizontal position, but require muscular support, as in sitting, the head droops, and the hands seek a support. Successively the senses of smelling, hearing, and touch pass away, as the sight has done; but, before this progress is completed, we start at any sound or disturbance, voluntary muscular action being instantly assumed, though in the midst of a surprise. We are nodding. If we are in the horizontal position, as in bed, the body is thrown into a form requiring the least muscular exertion—the limbs are semiflexed. As sight, smell, hearing, touch, again in succession fail, all voluntary motions cease, those which are now executed being of a purely automatic kind. The eyes are turned upward and inward, the iris is contracted,

the heart and the lungs act more slowly but more powerfully; a gentle delirium, which exists while the centres of the special senses are coming into repose, introduces us to profound and unconscious sleep.

This condition of profound sleep, though it may be quickly, is yet gradually reached by passing through certain well-marked stages. Once gained, we sleep with heaviness in the early part of the night, and more and more lightly as morning approaches. It would, however, be erroneous to suppose that this falling into insensibility and awakening are perfectly continuous events; there are, undoubtedly, subordinate periods of more and less complete repose, but under no circumstances are we ever aware that we are asleep.

Progress of night-sleep.

At any time of the night sleep may be abruptly broken, the mind resuming its power after passing through a momentary interval of confusion. Toward the close of the customary time, the senses resume their power in an order inverse to that in which they lost it—the touch, the hearing, the smell, the sight. For a short period after awakening, the organs seem to be in a state of unusual acuteness, more particularly that of sight—an effect arising from the obliteration of the vestiges of old impressions. From profound sleep we pass to the waking state through an intermediate condition of slumber. In the former, the movements which we may execute, under the influence of external impressions, are wholly of an automatic kind, such as turning in bed in various positions. The length of time spent in sleep and slumber respectively is by no means constant, many causes increasing the one at the expense of the other. On awakening, we are apt to indulge in certain muscular movements—we rub our eyes, stretch, and yawn. If we are suddenly aroused, our motions are feeble and uncertain on attempting to walk at once; but if we spontaneously awake at an unusual period, and more particularly if it be toward the morning, we commonly remark a clearness of intellect or mental power. Many of our most judicious and correct conclusions occur to us under these circumstances.

Manner of awakening.

Though it is said that the sleep of man lasts about eight hours, there are many variations. Authentic cases are on record in which individuals have, for a considerable time and apparently without injury, slept only for one hour, and others in which that state has been prolonged for an entire week. Man shows much greater differences than other animals; birds, for instance, sleep lightly, and cold-blooded animals generally profoundly. Since the object of sleep is to afford an opportunity for repairing the waste of the system, the length of the needful time depends on conditions that are themselves variable: the extent of the antecedent waste, and the rapidity of the repair. In winter we sleep longer and usually deeper than in summer, for the hourly waste in winter is greater. Habit, however, controls us very much.

Maximum and minimum length of sleep.

It has been supposed by some that it is to habit that our tendency to sleep at night is to be imputed. It is, however, more properly to be attributed to the ordinary circumstances of our life—the day being spent in muscular or mental exercise, since we can then see to perform our duties, and this tax upon the system being necessarily followed by a feeling of weariness. Those animals which seek their food in the dark sleep by day. It is not, therefore, to any external physical condition that we should impute our nocturnal sleep, but to the interior condition of our system, though it is quite true that physical agents, such as cold, and others that have been mentioned, will provoke a sensation of drowsiness.

Cause of night-sleep.

In sleep we require additional warmth, and this we obtain by instinctively using more clothing for the purpose of economizing the animal heat. The amount of caloric generated in the system is diminished through the cessation of muscular exercise, and therefore reduction of decay. The same may be said, to a certain extent, of the waste of the brain through its intellectual acts, and of the nervous system generally. This diminished amount of interstitial death corresponds with a diminished respiration, the hourly amount of oxygen consumed exhibiting a decline. The negro, who is much more sensitive than the white man to this decline of temperature, instinctively envelops his head with clothing, so that the air may be warmed by its contact therewith before it enters the respiratory organs. For the same reason, he sleeps with his head toward the fire, while the white man sleeps with his away. On similar principles we may account for the control which food has over sleep, the one seeming, to a certain degree, to replace the other. The French proverb says, "He who sleeps, dines," and this is true; for during sleep the waste of the system is reduced to a minimum, and the necessity for food correspondingly diminished. The quality of the food likewise exerts an influence on the length of sleep, for that which is of a nutritious kind, and easily assimilated, can more speedily execute whatever repairs the system may demand. It is probably owing to his variable diet that, even in a state of perfect health, man is so variable a sleeper, and that animals, the nature of whose food is so constant, sleep with so much uniformity.

Increased warmth required in sleep.

Uniformity of sleep connected with uniformity of food.

By some it has been supposed that the amount of sleep required by different animals is dependent upon the size of their brain; but if we keep in view that the object of sleep is the repair of waste, and that this is accomplished by the agency of the different mechanisms involved in organic life, we can easily see that such a statement can not be true. Its fallacy appears from common observation, apart from any physiological considerations. The brain of a turtle or of a serpent is relatively small,

and yet those animals sleep long and profoundly; but if we reflect on how many different conditions, external and internal, the repair of waste depends, we shall see that the time of sleep can not have any such arbitrary measure as that of the size of the brain. Among external causes which influence the rate of repair may be mentioned the digestibility of the food, some varieties of which, by reason of their chemical or physical qualities, yield more slowly than others. The internal causes are very numerous: the size of the digestive organs in relation to the body, and the energy with which their function is accomplished; the condition of development of the absorbent system, and the rapidity of its action; the rate of the circulation of the blood, which hurries the nutritive supply in its course; the amount of oxygen introduced into the system by the respiratory apparatus, which discharges, as we have elsewhere explained, the double function of removing the wasted products of decay, and of grouping into appropriate forms, so as to be available for their uses, the elements of nutrition that are being introduced. All these, and other conditions that might be named, determine the rate at which repair can be executed, and therefore the necessary duration of sleep. If, out of these various elements, we were to select one which would represent it, the activity of the respiratory organs would afford a more accurate measure than the size of the brain.

Conditions of the duration of sleep.

As the necessary repairs are accomplished, we pass through a condition of slumber, and our organs gradually awake in the manner that has been described. It is during this intermediate passage, that is, toward the morning chiefly, as the brain is resuming its functions, that dreams occur. They may, however, happen at any other period of the night, though then they are liable to present greater incongruities and more obvious violations of the proper order of events. It is quite correct that morning dreams are more likely to be prophetic, for they are more likely to be in themselves true.

Of dreams: their origin.

Dreams never strike us with surprise, no matter what may be the extraordinary scenery they present—no matter how great the violations of truth and reality. The dead may appear with the most astonishing clearness; their voices, perhaps long forgotten, may be heard; we may be transported to places where we have spent past years of our lives; combinations of the most grotesque and impossible kinds may be spread before us: we accept all as reality, perhaps not even suspecting that we dream. The germs from which have originated all these strange combinations are impressions stored up in the registering ganglia of the brain, more particularly in its optic thalami. These, as outward impressions have for the time ceased, are enabled to attract the attention of the mind, and emerge from their latent state. That all dreams originate in such

impressions is illustrated by the history of the blind, who still dream of things that they formerly saw. Thus it is stated that Huber, after he had been blind for fifty years, still dreamed of things he had seen when a boy. But little explanation can be given of the manner in which these vestiges may be grouped—a grouping which is so frequently in violation of all correctness that a dream which presents us with a logical sequence of events, and which we recognize on awakening to be naturally true, is sure to be an impressive one; and yet we can not doubt that the causes which suggest dreams are often purely physical, as when, in dropsy of the chest, the dreamer fancies he is drowning, or even suffers under the same delusion when his hand is dipped in water; or when a candle is carried into the room, and he awakens stricken with terror that the house is on fire; or, on the occurrence of noise, he believes that he is in a thunder-storm, or, perhaps, on a field of battle. Hence arises an automatism which becomes most striking when the dreamer answers questions put in a whisper to him, an incident of which cases are recorded in which individuals have revealed important events of their lives, which, when waking, they would never have divulged.

Automatic actions are usually considered as occurring without sensation, but this, in some instances, as in those now before us, can not be regarded as altogether true.

Deceptive appearance of truth in dreams.

Suggested thus by external circumstances, or arising spontaneously without any obvious cause, dreams pass before us with an air of truthfulness so imposing that we never suspect their fallacies. It may be truly said that they have a logic of their own. Indeed, so complete is the illusion, that instances are not wanting, and many have been recorded, in which, at the moment of awakening, the sleeper has been struck with the correctness of the conclusions at which he had arrived, and it was not until he had recovered from the delirious confusion of the moment, and reason had resumed her sway, that he perceived how incorrect they were. Thus great mathematicians have thought they had solved difficult problems, poets that they had composed stanzas of force and beauty; but these, on a moment's reflection, they have discovered to be an inconsequent flow of ideas, and mere nonsense. A few exceptions undoubtedly have occurred, as in the case of Mr. Coleridge, who affirms that, under these circumstances, he composed Kublai Khan, and remembered it in part on awaking. The French mathematician, Condorcet, makes the same statement with respect to several of his writings.

Instantaneous presentment of a long train of events.

One of the most extraordinary phenomena presented in the dreaming state is the instantaneous manner in which a long series of events may be offered to the mind, the exciting cause being truly of only a momentary duration. Some sudden noise

arouses us, and, in the act of waking, a long drama connected with that noise appears before us; or, in like manner, we are disturbed perhaps by a flash of lightning, and with that flash occurs a dream which seems to us to occupy a space of hours or even days, so many are the incidents with which it is filled. It has long been known that a like peculiarity has offered itself to those who have suffered by drowning, and have been subsequently restored. They have related that in their moment of supreme agony, the whole series of events of their past life has, as it were, flowed in an instant upon them with the most appalling vividness, their good and evil works, and even the most trifling incidents presenting themselves with distinctness—a tide of memory. And doubtless it is owing to like causes that, under the influence of opium or other narcotic drugs, the relations of space and time are so totally destroyed that we seem to live through a century in a single night, or to take in our view scenery, the distances and magnitudes of which are utterly beyond the reach of mortal vision. It has been truly said that the province of dreams is one of intense exaggeration. It is so in a double sense, for with equal facility we spread out a single and perhaps insignificant circumstance, so that it occupies the entire night, or we crowd a thousand strange, though perhaps connected, representations into the twinkling of an eye. Nor is it by any means the least extraordinary part of these wonderful facts that the mind occupies itself in an undiverted and unbroken manner for so long a time, with an insignificant idea in the one case, and perceives, with miraculous perspicuity, the rapidly disappearing occurrences in the other; that of a majority of dreams it retains no precise recollection, though they may have been presented with an intense energy, as we are assured from the impression of dread or melancholy, or even the physical results they have left, as when we awake and feel the heart throbbing violently and the whole frame trembling with terror, yet cannot, with the utmost exertion of memory, recollect what it was that we saw. The remembrance of dreams by no means, therefore, depends on the intensity of the impression that they made for the time; doubtless the majority of them are forgotten and can never be recalled. In some instances, which almost every one can recall, we dream a second time the same dream which we failed to remember when awake, and, it is said, even occasionally dream that we are dreaming.

The spreading of one idea over a long time.

Forgetfulness of dreams.

Our mental capability for recalling the scenes that have occupied us in our sleep is therefore dependent upon something more than the depth of the impression they have made. Whether it be, as some suppose, through an inertness of the mind, an incapability or indisposition of paying attention to the things thus presented to it, or whether it be that, through accidental causes, the vestiges of impressions remaining in the

optic thalami are brought out sometimes with more and sometimes with less force, there is every grade of intensity presented, from those floating indistinct aerial scenes, which seem scarcely to leave the slightest trace behind them, to those which, in spite of their outraging all reality, and even all probability, leave us in a horror-stricken state; such as, for example, the celebrated dream of the Emperor Caligula, in which he thought that the sea spoke to him. Yet there can be no doubt that in all these cases, no matter how indistinct or energetic, how false or how true, how harmonious as a whole, or how contradictory and grotesque, the elements of which all dreams are composed are impressions of things that we have seen or heard, or which have been otherwise submitted to the senses, the traces of which still remain imprinted in the registering ganglia of the brain. During the day, while we are exposed to light, and sounds, and other sources of disturbance, the impressions arising therefrom totally overpower, by reason of their newness and intensity, these ancient residues, so that the attention of the mind, in a state of health, is never directed to them; but when we close our eyes in the silence of night, all such external impressions are at an end, the organs of sense, sight, hearing, smell, and touch, are successively benumbed, and there is nothing to prevent the mind thus separated from outer things from occupying itself with these old impressions, any one or more of which, through accidental circumstances, presents itself in vigor, and a dream is the result.

Condition under which dreams arise.

The phenomena of dreams therefore illustrate, in a significant manner, the remarks that we have made respecting the functions of the cephalic ganglia of insects as magazines for the registry of impressions received by the organs of sense. No explanation of dreaming can be possibly given without admitting for a part of the human brain a like duty. The important advantages which accrue to our physiological explanations of the action of the human mind from the admission of this doctrine have already been dwelt upon.

Somnambulism.

Connected with dreams, and being, indeed, a dream carried into action, is somnambulism, or sleep-walking, of which there are several grades, from mere sleep-conversation and sleep-crying to the actual performance of difficult and even hazardous feats. The young infant evinces its discomforts by crying in its slumber, yet it can be comforted without awaking by the well-known voice of its mother. Children often show a propensity to talking in their sleep, and can sometimes be brought to give a few rational replies to inquiries put to them. At their time of life, the disposition is more frequently manifested to get out of bed and move about the house, or even out into the open air under the influence of a dream. When sleep-walking occurs in the adult, it is liable to be accompanied by actions of an apparently connected kind, though

their object may be quite trivial, and in its attainment considerable risks may be run. In these cases it seems as if the mind was absolutely wrapped up in one idea, and wholly unable to comprehend any thing else. If the eyes of the somnambulist are wide open, he sees nothing, and even though a bright light be presented before him, the iris will not contract, yet he moves about in a manner as if he were, in one respect, guided by understanding, the air of his movements being as if he knew what he was about, yet in another respect as though he was impelled by the most unaccountable folly, walking along the roof of the house, seating himself on the chimney, and finding his way in safety over precipitous places, past which it would be impossible he should go if awake, no matter how steady his head might be. Besides this complete condition of somnambulism there are intermediate forms, during which the various senses of seeing, hearing, etc., are in partial activity. There are also differences in the intensity or depth of the state, as is shown by the ease or difficulty with which the individual is aroused; sometimes to speak to him is enough, sometimes he must be violently shaken or otherwise roughly treated. It has been observed in some cases that where the patient spontaneously wakens under circumstances that affright him, he is at once broken of the habit.

Sensation of falling.

With dreams and somnambulism is also to be classed that sensation which often surprises and disturbs us when we are just passing into sleep, a sensation as though we were suddenly falling down stairs. This, with some persons, is of almost nightly occurrence. Its opposite, an inability to move, as though we were oppressed by some great weight, or spell-bound in some incomprehensible way, is nightmare.

Nightmare: its causes.

In this distressing affection there is a sense of oppression at the epigastrium, and a difficulty, or rather impossibility, of moving or speaking. A frightful dream, in which some alarming object is depicted with intolerable distinctness, accompanies these symptoms, the attack terminating by a struggle to shake off the object of dread, or to escape by flight, or to speak. On awaking, the sufferer finds himself trembling with terror, the respiration hurried, and the heart throbbing violently. The intellectual faculties are on different occasions in various states of activity, and sometimes the dream, and our actions consequent upon it, offer no violation of reason. Indeed, some individuals are affected by this trouble during the daytime, when they are wide awake and perfectly aware of what is going on; but, whether it occurs by night or by day, the sentiment with which it oppresses is that of unspeakable dread. Even at night we sometimes are conscious of its approach, when we are in the intermediate state between sleeping and waking.

The cause of nightmare, in all its variety of forms, is disturbance of the respiratory function, which, by interfering with the arterialization of

the blood, affects the brain. This disturbance may be brought on in many ways, as by the pressure of the stomach after a hearty supper, or in diseased conditions, such as hydrothorax; but it is popularly supposed, where these morbid conditions are not obviously concerned, to be attributed to sleeping on the back. Though this is undoubtedly true in a great many instances, it is very far from being an essential condition, for nightmare may occur in any position that the sleeper may possibly assume. The restraint upon the arterialization of the blood, which appears to be its essential condition, interferes with the circulation through the lungs on the principles that have been described in a preceding chapter, nor can the heart force a passage, however violently it may throb. The effect depends not so much upon the apparent rate and power with which the respiration is going on, for any embarrassment or difficulty in the introduction of air merely leads to snoring, which is in no manner connected with nightmare. The cause of this latter affection is to be sought for in the air-cells, which are unable to rid themselves, with their accustomed facility, of the carbonic acid and other effete products of respiration which they contain.

2D. OF DEATH.

At all periods of life, the functional activity of the system occasions a waste of its tissues by the interstitial death of their parts, and therefore involves a necessity of repair. So long as the reparation balances the waste, a healthy equilibrium is maintained; but when the nutritive powers decline, as old age approaches, a gradual deterioration of the system ensues.

Condition of healthy equilibrium.

The period of greatest activity is also that of greatest waste, and of the most active and perfect repair, interstitial death and the removal of decayed material then occurring in the most rapid manner. The energy of life is thus dependent on the amount and completeness of death.

At a later period, with advancing years, although the loss of substance through functional activity may be lessened, the renewal and restoration of the portions which are necessarily consumed are far more than correspondingly diminished. We thus become incapacitated corporeally and mentally, and, if no accident intervenes, we die through mere old age.

On several occasions we have already noticed the analogy between the life of individuals and that of species. An analogy also may be traced in the circumstances and causes of their death, for the discoveries of geology abundantly show that thousands of species in the organic series have become extinct. The death of a constituent molecule in an animal body, the death of the individual animal itself, the death of the species to which it belongs, are all philosophical facts of the same kind, though presenting, perhaps, in

Death of a molecule, of an individual organism, of a species.

their aspect a difference of interest and importance. The death of individuals, as has been said, may occur in two ways, by accident or by old age. But death from old age is very unusual, for even in the cases of those who are very far advanced in life, its close is ordinarily brought about by some lesion or derangement of the vital organs, thus, in reality, constituting accidental death.

Death from accident and by old age.

Most men desire that their final scene may be attended with as little derangement as possible of their ordinary mental powers, and that it may be very brief. If this constitute the euthanasia, or happy death, it certainly can not be thought that extreme old age is desirable, constituting, as it does, a long-continued and dreary disease. The senses fail us in the same manner and in the same order that they do when we are falling asleep, their gradual deterioration bringing us back to the helplessness and imbecility of infancy. In the long interval during which this is going on, the aged man is not only a burden to himself, but a sad spectacle to every one around him; his perceptions are being gradually blunted; and though he is, as it were, by degrees passing into a final slumber, it is in that disturbed way which all have experienced when they fall asleep after severe fatigue.

Euthanasia.

The different portions of the body die in succession: the system of animal life before that of organic, and of the former the sensory functions fail first, voluntary motion next, while the power of muscular contraction under external stimulus still feebly continues. The blood, in gradual death, first ceases to reach the extremities, its pulsations becoming less and less energetic, so that, failing to gain the periphery, it passes but a little way from the heart; the feet and hands become cold as the circulating fluid leaves them, the decline of temperature gradually invading the interior. No one has ever yet offered a more accurate picture of the appearance of the dying than that presented by Hippocrates: "If the patient lies on his back, his arms stretched out, and his legs hanging down, it is a sign of great weakness; when he slides down in the bed it denotes death. If, in a burning fever, he is continually feeling about with his hands and fingers, and moves them up before his face and eyes as if he were going to take away something before them, or on his bed-covering as if he was picking or searching for little straws, or taking away some speck, or drawing out little flocks of wool, all this is a sign that he is delirious, and that he will die. When his lips hang relaxed and cold, when he can not bear the light, when he sheds tears involuntarily, when, dozing, some part of the white of the eye is seen, unless he usually sleeps in that manner, these signs prognosticate danger. When his eyes are sparkling, fierce, and fixed, he is delirious, or soon will be so; when they are deadened, as it were, with a mist spread over them, or their brightness lost, it presages death or

Gradual death.

The Hippocratic face.

great weakness. When the patient has his nose sharp, his eyes sunk, his temples hollow, his ears cold and contracted, the skin of his forehead tense and dry, and the color of his face tending to a pale green or leaden tint, one may give out for certain that death is very near, unless the strength of the patient has been exhausted all at once by long watchings, or by a looseness, or being a long time without eating."

Post-mortem organic functions and passions.

Even after death some of the organic functions continue for a time, more particularly secretion and the development of heat. In a former chapter, page 444, the capability of extraordinary muscular motions has been referred to. From other interesting observations on those who have been instantaneously decapitated by the guillotine, it has been asserted that the body can display what has been termed post-mortem passion and resentment. It may, however, be doubted whether this is really true. Perhaps these effects are only analogous to those convulsive manifestations which may be easily produced, in an intensely interesting way, by the application of voltaic batteries to those who have been dead for some time.

Insensibility before the final agony.

Physiologists often quote the sentiment of Montaigne, "With how little anxiety do we lose the consciousness of light and of ourselves." By this they would convey the idea that the act of dying is as painless as the act of falling asleep, and also as little perceived. They recall the fact which seems to support this view, that those who have been recovered after apparent death from drowning, and after sensation has been totally lost, report that they have experienced no pain; and, indeed, when we reflect that the sensory powers are the first to decline, the eye and the ear, at an early period in the article of death, failing to discharge their duty, and the general sense of touch becoming rapidly more and more obtuse, we can scarcely put any other interpretation upon the final struggles which constitute what is so significantly called the agony, than that they are purely automatic and therefore unfelt. Doubtless the mind, in this solemn moment, is sometimes occupied with an instantaneous review of impressions long before made upon the brain, and which offer themselves with clearness and energy now that present circumstances are failing to excite its attention, through loss of sensorial power of the peripheral organs, this state of things having also been testified to by those who have been recovered from drowning.

Life closes at last in various ways. Some pass away as though they were really falling asleep; others with a deep sigh or groan; others with a gasp; and some with a convulsive struggle.

CHAPTER VII.

ON THE INFLUENCE OF PHYSICAL AGENTS ON THE ASPECT AND FORM OF MAN AND ON HIS INTELLECTUAL QUALITIES.

Differences in Form, Habits, and Color of Men.—Ideal Type of Man.—Its Ascent and Descent.—Causes of these Variations.

Doctrine of the Unity of the Human Race.—Doctrine of its Origin from many Centres.

Influence of Heat on Complexion.—Cause of Climate Variations.—Influence of Heat illustrated by the cases of the Indo-Europeans, the Mongols, the American Indians, and the Africans.—Distribution of Complexion in the Tropical Races.

Variations in the Skeleton.—Four Modes of examining the Skull.—Connection of the Shape of the Skull and Manner of Life.—Physical Causes of Variation of the Skull.

Influence of the Action of the Liver on Complexion.—Influence of the Action of the Liver on the Form of the Skull.—Base Form of Skull arising from Low as well as High Temperatures.—Disappearance of the Red-haired and Blue-eyed Men in Europe.

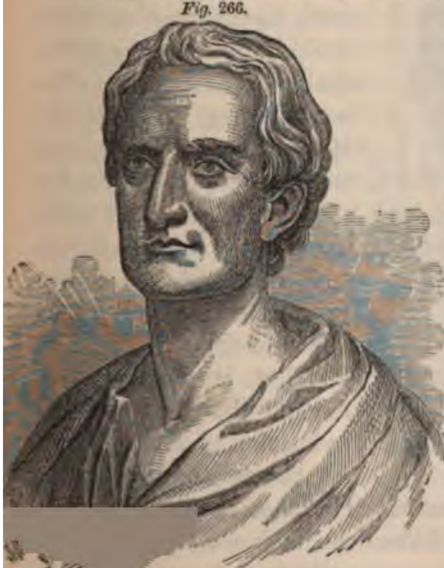
The Intellectual Qualities of Nations.—Synthetical Mind of the Asiatic.—Analytical Mind of the European.—Their respective Contributions to Human Civilization.—Spread of Mohammedanism in Africa.—Spread of Christianity in America.—Manner of the Progress of all Nations in Civilization.

THERE are great differences in the aspect of men.

Differences in form, color, and dispositions of men.

The portrait of Newton is from the frontispiece of his immortal Principia. "Does he eat, and drink, and sleep, like other people?" ask-

Fig. 266.



Sir Isaac Newton.

Fig. 267.

Australian.

ed the Marquis de l'Hôpital, himself a great contemporary French math-

ematician: "I represent him to myself as a celestial genius entirely disengaged from matter." And, truly, transcendent intellect shines out in every lineament of that noble countenance.

What a contrast between the astronomer, of whom the human race may be justly proud, and the Australian savage whose portrait Dr. Prichard has furnished! This man lives in a hollow tree, which he has in part excavated by fire, and obtains a precarious support from shell-fish, or bruised ants and grass. He can make a hook of a piece of oyster, and can fasten a line to it. He is lost in filth and vermin. His life is like that of a beast; it is concerned only with to-day. The early navigators accused him of cannibalism. We can not say that his features acquit him of the charge.

History teaches us that a nation may pass through an ascending or descending career. It may, by long-continued mental culture, exhibit a general mental advance, and under such circumstances may produce, here and there, an intellect of the first order; or it may go through a course of degradation until it reaches conditions inconsistent with its continued existence, and then it dies out.

Man is accordingly distributed over the face of the earth in various conditions. Here he presents the civilization of the European, there the abject misery of the Australian. What more humiliating spectacle could be offered to us than the annexed engraving, *Figure* 268, from M. d'Urville? Even a negro of Guinea might look down on such a specimen of human imbecility and physical weakness with contempt, and refuse to recognize such a being as a man at all.

Fig. 268.

Australians.

What is it that has brought this man and his companion to such a pass? An almost tropical sun, a pestilential climate, starvation, nakedness, the want of shelter, personal fear: these have done their work on the successive generations of his miserable ancestors, who have been forced from step to step in a descending career, and here is the result.

Causes of these differences.

Among the causes which influence the aspect of man, there are two

which are pre-eminent: heat determines his complexion; social condition the form of his brain, and, therefore, that of his skull.

The aspect of man in form and color oscillates between two extremes. Submitted for a due time to a high temperature, any race, irrespectively of its original color, will become dark; or if to a low temperature, it will become fair. Under such conditions as will be set forth in this chapter, it will pass to the elliptical; under others, to the prognathous form of skull. No race is in a state of absolute equilibrium, or able successfully to maintain its present physiognomy, if the circumstances under which it lives undergo a change. It holds itself ready, with equal facility, to descend to a baser, or rise to a more elevated state, in correspondence with those circumstances.

Ascent and descent of human organization.

I think that this principle has not been recognized with sufficient distinctness by those who have studied the natural history of man. They have occupied themselves too completely with the idea of fixity in the aspect of human families, and have treated of them as though they were perfectly and definitely distinct, or in a condition of equilibrium. They have described them as they are found in the various countries of the globe, and since these descriptions remain correct during a long time, the general inference of an invariability has gathered strength, until some writers are to be found who suppose that there have been as many separate creations of man as there are races which can be distinguished from each other. We are perpetually mistaking the slow movements of Nature for absolute rest. We confound temporary equilibration with final equilibrium.

Man can not occupy a new climate without an organic change occurring in his economy, which by degrees comes to a correspondence with the conditions by which it is surrounded. In this career, each individual, as a member of one generation, may only make a partial advance, for differentiation most commonly occurs in the early periods of embryonic life, as described at page 505; but, since all individual peculiarities are liable to hereditary transmission, the cumulative effect becomes strongly marked at last. So dominating is the control which physical influences exert over us, that invariability of our aspect for several generations may be received as a proof that those influences have been stationary in kind and degree. In such a perfect manner is that aspect dependent on them that it is truly their representative. If they change, it must change too.

Correspondence of climate and organization.

I do not, therefore, contemplate the human race as consisting of varieties, much less of distinct species, but rather as offering numberless representations of the different forms which an ideal type can be made to assume under exposure to different conditions. I believe that that ideal type may still be recognized, even in cases that offer, when

Ideal type of man.

compared together, complete discordances; and that, if such an illustration be permissible, it is like a general expression in algebra, which gives rise to different results according as we assign different values to its quantities, yet in every one of those results the original expression exists.

From this it therefore follows that there is a capability of metamorphosis or transmutation from form to form; that the human system possesses no inherent resistance to change, no physiological inertia, but will pass indifferently upward and downward, toward perfection or toward degradation, as circumstances overrule, yet is it the same human system throughout. Nor is it of any consequence that the progress of these changes may be, as we term them, tardy, and that for their completion a long time may be required. Even a mass of inorganic matter — a rock — transferred from the equator toward the pole, or from the pole to the equator, would not change its temperature to that of the new locality at once; it would come to its destined equilibrium in a gradual way, in a time depending on its mass and conducting power. We should not impute its slow manner of yielding to any inherent principle of resistance which it possessed. The physiological metamorphosis of man is an affair of centuries. The universal recognition of the principle that such changes are possible lies at the bottom of all our attempts to elevate communities by ameliorating their social condition and by education.

Time required for physiological change.

In the remarks which follow, it will therefore be understood that I receive the classifications of Blumenbach and other authors as offering a convenience in description, but do not attach to them any essential significance.

Though plants and animals are limited to certain localities of the earth's surface, some species being formed in one and some in another region, the human family lives indifferently all over the surface of the globe. It occupies countries where the thermometer falls to 50° below zero, or where the temperature of the midday sun is 160°. In these different climates, the most marked differences in color, stature, conformation, and habits are exhibited, there being every shade, from a jet black to a fair white; every stature, from the pigmy Esquimaux and Laplanders to the tall Patagonian; every variety of facial angle, from that acute one which characterizes the ape to the classical aspect of the Greek, which is more than 90°; every pursuit of life, hunting, fishing, the keeping of flocks, agriculture, commerce, and the arts of civilized society. To these might be added the use of every variety of food, from a wretched subsistence on worms and roots scratched out of the ground to the luxurious habits of the epicure; every grade of locomotion, from those who never leave the hill or valley where they were born to those who are perpetually wandering all over a continent, nay, even all over

Habits of different nations.

the globe. There might, too, be added every variety of character and every degree of intellectuality. Among these differences, the variations of language are by no means the least important. It is estimated that more than three thousand dialects are spoken.

Among these races certain common traditions prevail, historical reminiscences handed down from one generation to another, which convey the deeds of former great men who have either distinguished themselves by their achievements in war or by their inventions in the peaceful arts; traditions which have also communicated the religion or the superstition of the ancient times, and which, among people inhabiting countries remote from one another, present such an aspect of sameness, that we must either refer them to one common and more ancient source, or regard them as arising from analogous peculiarities in the mental structure of the whole race.

Traditions of nations.

There can not be a doubt that in the lapse of many ages the influence of external physical agents must have made a marked impression upon the original characters of men. Few questions have been more critically discussed than the extent to which this change of aspect by physical agents can go, many naturalists believing that the sole cause of national difference is the influence of climate or temperature—an influence which is sufficient to account for all other organic peculiarities we have just specified; for if we admit that the same original germ may develop itself into countless forms, according as it has been exposed to different physical agents, much more is it probable that the various races composing the human family, exposed as they have been to different physical circumstances, may by degrees have assumed the discordant features they present, although they have descended from one original stock.

Influence of external agents on nations.

Here we shall have to consider the weight which should be attached to a very remarkable observation which has of late been made as respects the distribution of man. With regard to plants, it has long been known that they are grouped round certain centres, which may be regarded as their foci of origin, and one of such groups compared with another presents striking contrasts; the vegetation of Central Africa is wholly distinct from that of Europe, the vegetation of Europe distinct from that of North America, and this, again, from New Holland. There are no laurinæ in Central Africa, no heaths in the New World. The forests of New Holland gain their most striking features from their leafless acacias and eucalypti. So, in like manner, there are foci of origin and circles of distribution as regards animal life. The fauna of Asia is wholly dissimilar from that of Europe, the fauna of Europe is dissimilar from that of North America, and this, again, from that of Africa and New Holland. Without specifying details, we

Geographical distribution of plants, animals, and man.

may recall that the hippopotamus and camelopard are natives of Africa, and are restricted to it; the tiger is a native of India; the armadillos and ant-eaters, of South America; the kangaroo and ornithorhynchus, of New Holland. The earth's surface might thus be divided into regions or realms, each possessing its own special flora and fauna. And more than this, the oceans, too, might in like manner be parted off, and this not only as regards their surface, but also in strata at different depths. Now these botanical centres and circles are coincident with the zoological centres and circles, and hence there has arisen the idea that such centres have been truly points of original development, both for one and the other of these natural kingdoms, and that the globe has not been filled by a process of dispersion or diffusion from one point, but co-ordinately, and, perhaps, contemporaneously from many such foci, and that we can still recognize the position of these foci by a critical study of animals and plants.

The two hypotheses of the origin of nations.

As to the discussions which have of late years arisen on this question, the reader may refer to the work of Drs. Nott and Gliddon on the types of mankind for arguments in support of a multitude of centres of human origin, and to that of Dr. Prichard on the natural history of man for those in behalf of the unity of the race. In these works, respectively, will be found most of the facts hitherto brought forward.

Doctrine of Professor Agassiz.

In the former of these works, Professor Agassiz draws attention to the circumstance that all around the Arctic circle, and therefore in every longitude, is to be found one race offering characters that are strikingly homogeneous in aspect, intellect, and habits of life, represented in America by the Esquimaux, in Europe by the Laplanders, and in Asia by the Samoiedes. These live in a region of which the fauna and flora are likewise homogeneous. It has every where the same dreary expanses, covered with dwarf birches, mosses, and lichens; in its waters there are the same fishes, as the salmon, and the same molluscs and echinoderms. In the air it has the same birds. Among its mammals found thus with uniformity, the white bear, the reindeer, the walrus, and the whale may be mentioned. With a special fauna thus coinciding with a special flora, there is also a special variety of man.

Floral, faunal, and human groups.

What has here been said respecting Arctic life may be generalized. Each of the coincident floral and faunal circles has its own species of man.

Thus, in the temperate zone, may be distinguished three such primary realms, each of which is distinct as regards its botany and zoology; and, in correspondence, we find that in the first, in the country of the *Mongolians*, to the east beyond the Caspian Sea, there are nations whose com-

plexion is yellow; in the second, upon the shore of the Mediterranean and throughout Europe, there are others whose complexion is white; in the third, in America, others whose complexion is red; and though these three widely-extended races touch, upon their north boundary, the homogenous Arctic inhabitants, in every respect they may be distinguished from them. The temperature of the zone in which they live ranges from 32° to 74°; it permits the growth of pines, nut and fruit trees, and among its animals might be mentioned the bear, the wolf, the otter, the deer, the squirrel, and the rat; these animals, however, respectively exhibiting striking differences characteristic of their three focal centres: the black bear belongs to North America, the brown bear to Europe, and the bear of Thibet to Asia. The European stag finds its American analogue in the wapiti, and in Asia in the musk deer. The wild ox of Lithuania differs from the North American buffalo, and this, again, from the Mongolian yak. Even among plants the same differences may be traced; the pines of Europe are not the same as the pines of America, and thus it would appear that each of the three great organic circles belonging to the temperate zone has a flora, a fauna, and a human species of its own.

The same general result might be established for the tropical regions, and special centres assigned for Africa, Malaya, and Polynesia.

In view of this distribution as connected with habits, Dr. Prichard thus expresses himself in his Natural History of Man: "Let us imagine, for a moment, a stranger from another planet to visit our globe, and to contemplate and compare the manners of its inhabitants, and let him first witness some brilliant spectacle in one of the highly-civilized countries of Europe: the coronation of a monarch, the installation of St. Louis on the throne of his ancestors, surrounded by an august assembly of peers, and barons, and mitred abbots, anointed from the cruise of sacred oil brought by an angel to ratify the divine privilege of kings; let the same person be carried into a hamlet in Negroland, in the hour when the sable race recreate themselves with dancing and barbarous music; let him then be transported to the saline plains over which bald and tawny Mongols roam, differing but little in hue from the yellow soil of their steppes, brightened by the saffron flowers of the iris and tulip; let him be placed near the solitary den of the Bushman, where the lean and hungry savage crouches in silence like a beast of prey, watching with fixed eyes the creatures which enter his pitfall, or the insects and reptiles which chance brings within his grasp; let the traveler be carried into the midst of an Australian forest, where the squalid companions of kangaroos may be seen crawling in procession in imitation of quadrupeds; can it be supposed that such a person would conclude the various groups of beings whom he had surveyed to be of one nature, one

Habits of nations.

tribe, or the offspring of the same original stock? It is much more probable that he would arrive at an opposite conclusion."

On this it may be remarked that much would depend on the previous training of the illustrious stranger. If his mind had been imbued with a better philosophy than that which prevails in this our lower world, he might look with an equal eye on the transitory fashions before him, and penetrate to the first principles of things through the false glare of pomp or through debasement and degradation, and so arrive at a conclusion precisely the opposite of the foregoing, in the same manner as has Dr. Prichard himself.

For, from such an elevated point of view, the plumed pageant of civilized life might only appear to be a modified phase of the ceremonials of equinoctial Africa, where the inhabitants, on their festive occasions, adorn their naked bodies with leaves, and present oblations of palm oil with many genuflexions to their chiefs and enchanters. Beneath the feathers in the one case, and the leaves in the other, he might discern the same ruling idea, and detect the same human nature; or, if his vision could reach into the past, and recall the credulous Greek worshiping before the exquisitely perfect statues of the deities of his country, beseeching them for sunshine or for rain, and then turn to the savage Amaiman, who commences his fasts by taking a vomit, and, for want of a better goddess, adores a dried cow's tail, imploring it for all earthly goods, and particularly to pay his debts—again the same principle would emerge, only illustrated by the circumstance that the savage is more thorough, more earnest in his work.

Resemblances among nations.

In fact, wherever we look, man is the same. Stripped of exterior coverings, there is in every climate a common body and a common mind. Are not all of us liable to the same diseases? Have not all a tendency to exist the same length of time? Is it the temperature of our body, the beat of the pulse, the respiration that we observe—are they not every where alike? Or, turning to the manifestations of the mind, is there not, among all the tribes of our race, a belief in the existence and goodness of God? in unseen agents, intermediate between him and ourselves? and in a future life? Do we not all put a reliance in the efficacy of prayers? and all, in our youth, have a dread of ghosts? How many of us, in all parts of the world, attach a value to pilgrimages, sacrificial offerings, fastings, and unlucky days, and in our worldly proceedings are guided by codes of law and ideas of the nature of property! Have we not all the same fears, the same delights, the same aversions, and do we not resort to the use of fire, domestic animals, and weapons? Do we not all expect that the differences which surround us here will be balanced hereafter, and that there are rewards and punishments? Is there not a common interpretation of all the varied forms of

funeral ceremonies? a common sentiment of the sacredness of the tomb? Have we not always, and do we not every where set apart a sacerdotal order, who may mediate for us? In our less advanced civilization, do we not all believe in sorceries, witches, and charms? It signifies nothing in what particular form our mental conceptions are embodied; it is the conception that concerns us, and not the aspect it has assumed. Thus equally do the views of the various nations demonstrate their innate belief of a future world—the undisturbed hunting-ground of the American Indian, the voluptuous Paradise and society of the houris of the Arabian, or the snow hut of the Esquimaux, in which the righteous feed on the blubber of whales.

Influence of temperature on the complexion.

Turning our attention to the influence of temperature, it may be observed that the development of coloring matter in the skin depends on the heat to which we are exposed. Generally, it might therefore appear that there should be a correspondence between the complexion and the latitude of the place of our abode, the skin being darker as we approach the equator, and fairer toward the poles, because, since all the heat that we receive comes from the sun, the amount which is furnished to us depends upon the obliquity of his rays, and therefore upon the latitude. But this is true only in a very general way, and many exceptions at once spontaneously suggest themselves. I may point out some of these variations.

Causes of local temperatures.

The temperature of a place depends on three leading circumstances, its latitude, its elevation above the sea, and on meteorological conditions. Respecting the latitude, nothing need be added to the remarks already offered; and as regards the influence of elevation above the sea, it is to be remembered that there is a decline of temperature as we ascend in the atmosphere from any point of the globe, and for this reason, as has been already explained at page 473, even under the equator there will be an arrangement answering to climates on every high mountain, its top, if sufficiently elevated, being covered with perpetual snow. Of meteorological conditions, it may be said that they are so numerous as to render it almost impossible to give a full and yet brief statement of them, but as illustrations may be mentioned the proximity of the sea, or of great desert tracts, ocean currents, the prevailing winds; thus, in our hemisphere, a north wind predominating lowers the mean temperature of the place, a south wind tends to raise it; and thus, also, the great desert of Sahara and the American Gulf Stream increase by many degrees the temperature of Europe.

For such reasons, therefore, the lines of equal heat do not correspond to the parallels of latitude, but, as an inspection of a chart of them will show, deviate greatly therefrom.

In treating of the influence of heat on plants, it was shown that, when

we make our examination in a critical manner, the problem is not so simple as appears at first sight, and that there are several different relations of the heat which must be considered. Thus the geography of plants is not wholly determined by the mean temperature of the whole year, nor by the greatest heat of the summer, nor the greatest cold of winter; that is to say, it neither follows the isothermal, isotheral, nor isochimenal lines. Moreover, the luxuriance of vegetation is not so much dependent upon the temperature or intensity of heat as it is upon the quantity. These remarks apply with much force to the case now before us, for the change of complexion is not so much dependent upon the intensity of heat determined by the thermometer as it is upon the absolute annual quantity; for, though these conditions of intensity and quantity of heat are essentially distinct, yet it will generally happen that they may increase or diminish together, without there being an absolute correspondence between them. There can be no doubt that the quantity of heat annually furnished in Guinea vastly exceeds the quantity annually furnished to any part of tropical America. It is upon this condition, and not upon the height of the thermometer, that the darkening of the human complexion depends.

Intensity and quantity of heat compared.

To the reader who is not familiar with the technicalities of Natural Philosophy, an explanatory illustration of the statement here made may be of value. If he will suppose that he examines a wine-glass of water, boiling hot, and a gallon of tepid water by a thermometer, he will find that that instrument will stand much higher in the wine-glass than in the gallon. But if he proceeds to determine how much ice the two portions of water will respectively melt, he will find that the greatest effect is produced by the lukewarm water. We say, therefore, that though the thermometer has indicated the intensity of the heat in the two portions of water respectively, that is to say, their temperatures, it has not indicated the quantity present in each, but the melting of the ice has revealed the fact that the tepid water, by reason of its larger proportion, contains a larger quantity of heat.

It may be repeated, therefore, that the absolute quantity of heat annually furnished to any locality is by no means indicated by the maximum height to which the thermometer will rise in the summer season, yet it is upon that condition, quantity, that the tint of the complexion depends.

That climate does thus influence color is clearly demonstrated by the fact that a family of men, indisputably derived from a common stock, have different complexions in different countries. The Jews of the north of Europe are fair men, often having red beards and blue eyes. As we trace them in their southeasterly distribution, their color deepens by degrees. In their original country they

Quantity of heat influences complexion.

are tawny, still farther on they are deep brown, and in Malabar almost black. A more interesting and more general instance is offered by the race to which we belong, the Indo-European, which reaches, in one unbroken column, across Western Asia, through Europe, from Hindostan to the British Islands. That this is one homogeneous family, derived from a common stock, is proved beyond all possibility of a doubt by the affinities of its languages, all showing a relation to the ancient Sanscrit, and even betraying, by their varied designations of certain objects, in an approximate manner, the time at which the progress of this column was made—that it was anterior to the introduction of the metals, in the age of stone, as some authors have designated it, when weapons and implements of that material alone were employed, for the names of the metals are different in many of the different languages of this race.

Variations impressed on the Indo-European race.

But how is it as regards the complexion of the Indo-Europeans? To the northwest it is light, but it darkens toward the extreme southeast in India, the distribution in this respect having been doubtless much better marked in former times, before it was disturbed by the influences of civilization. Thus the Roman authors speak of the northern Germans, of the Britons, and the Gauls, as being red-haired, blue-eyed, and very light in their complexion. It is not to be understood, however, that the tint deepens through various shades of olive and brown by a steady progress as we pass toward India, for the physical principles on which we have been dwelling would prepare us to expect that, whenever we reach regions more elevated above the level of the sea, the complexion of the natives will be lighter. For this reason, the inhabitants of the range of the Caucasus, and again those of the great elevations of the Himmalaya Mountains and sources of the Ganges, are as light as the southern Europeans, and there very frequently is seen the auburn-bearded, and blue or gray eyed man.

Fig. 269.

Brahmin.

While the complexion thus depends on the heat, the form of the skull is determined by the condition of development of the brain, and this is the more perfect where life is maintained in circumstances of

plenty, indolence, luxury, ease. In Hindostan, among the natives of high caste, have from time to time arisen men whose mental endowments have been in no respect inferior to those of Europeans—statesmen, poets, soldiers, astronomers, mathematicians. Complexion apart, the portrait of Ram Ruttum, a Brahmin, *Fig.* 269, taken by Mr. Branwhite, presents an intelligent and agreeable countenance, though, perhaps, with an air of effeminacy.

Variations impressed on the Mongol race.

Let us examine a second of our subdivisions, the Mongol, characterized as descending from a common stock by the affinities of its languages, though having a geographical distribution from the Indian Ocean to the shores of the Polar Sea. As with the Indo-European race, so with this, the color becomes darker as the tropic is approached—so dark, indeed, that, in the lowest latitudes to which its nations reach, they may be said to be black. From this they pass through various shades of brown and olive as a progress to the higher latitudes is made, the pale countenance reappearing in North Tartary, and attaining to whiteness in the fish-feeding tribes, Samoiedes, on the shores of the Icy Sea. But here, again, the complexion and the latitude are not in correspondence: on the low shores of China the natives are tawny, but in the mountainous regions of the northwest of that country there are tribes spoken of by those who have seen them as of surprising whiteness, and a similar circumstance occurs among the Tartar tribes of the very elevated plateaux of Central Asia.

Although the Chinese countenance, both of the indigenous race and the dominant Tartars, is very characteristic, as seen in the annexed portrait, *Fig.* 270, from Dr. Prichard, the form of the skull expresses a high intellectual culture, of which also their civilization and their polity are a surprising proof. The difficulties of governing masses of men concentrated in a narrow space seem, by the statesmen of that nation, to have been in a great measure overcome. On the Chinese rivers there are many great cities, vastly outnumbering in their population the largest European capitals. Under the government of the emperor, it is said that there live, in security and repose, one third of the human race! Such a spectacle may impress even the philosopher with sentiments of respect and admiration.

Fig. 270.

Chinese.

The hardships of life have left their impression on the form of the skull of the North Asiatic, whose energies have to be directed to the support of

Fig. 271.

Kamtschatdale.

animal existence. The portrait of a Kamtschatdale, *Fig.* 271, selected by Dr. Prichard as an example, shows the projecting muzzle, that invariable index of want, and true animal feature. The complexion is nevertheless in correspondence with the low temperature of the country.

Variations impressed on the American Indian race.

A like examination of a third of the subdivisions of men, the American, equally well illustrates the influence of heat. These, though popularly spoken ed, and often regarded as presenting the same color from the North Sea to Terra del Fuego, are very far from offering such a uniform- The Esquimaux on the north, and the Fuegians on the south, are he tint of the native races deepening, to a certain degree, as the r is approached—a gradual deepening, much better marked in than in North America, and on the Pacific than on the Atlantic

Fig. 272.

American Indian.

slope. As examples of the North American Indians, we may take the portraits, by Mr. Catlin, of Black Hawk, *Fig.* 272, and Tuchee, *Fig.* 273, page 576; the former a Sac, the latter a Cherokee. It is sufficient to compare the countenances of these Indians with those of California, as figured in the Voyage Pittoresque of Choris, *Fig.* 274, page 576, to realize how erroneous is the prevalent statement that all the American tribes, both of the north and south continent, are alike. The ol- ck Indians of the Pacific slope, though their lips are thick and oses flat, have lank and not woolly hair, *Fig.* 275, page 576. On lantic shore, as is well known, the temperature, in passing to lower

Fig. 273.

American Indian.

latitudes, does not so rapidly vary; and on the Pacific the mean heat is much higher than on the Atlantic

Fig. 274.

California Indian.

for the same parallel of latitude.

Fig. 275.

California Indians.

In South America, the so-called red race, as we have just observed, is deeper in complexion as we pass from Terra del Fuego and Patagonia northward toward the line. The Chilians are darker than the Fuegians, and the Peruvians darker than the Chilians. As the topographical construction of that continent would lead us to infer, there is an analogous distribution from west to east, crossing the preceding at right angles; the Inca race, who inhabit the plateaux of the Andes, are lighter than

corresponds to the latitude; but from this point, passing to the east, the Brazilio-Guarani are darker as we approach the Atlantic Ocean. It may with truth be said that the intervention of the Gulf of Mexico and Caribbean Sea has lightened the complexion of the aboriginal tribes of North and South America.

In the last place, we may consider, in like manner, the African races. These are, as we should expect from the high temperature of that continent, all dark, yet not equally so, for the Berbers toward the Mediterranean shore, and the Hottentots and Kaffirs adjacent to the Cape of Good Hope, are of a lighter hue. In this class we ought also to enumerate, as an example of no common interest, the native Egyptians, who are, perhaps, the lightest of all. It does not appear that there has been any marked change in the complexion of the aboriginal Egyptian for the last three thousand years, so far as can be judged from a comparison of the descriptions and paintings which have descended to our times, with the existing Copts. Leaving the Mediterranean shore, and advancing to the south, we pass through bands of population sensibly becoming darker, save where a disturbance arises by reason of the elevation of the mountain ranges. On the north of the equator the negro land is not reached until we are within 10° latitude. The true negro occupies a zone crossing through the continent west and east. If our examination be made meridionally, in the manner just supposed, but along the Red Sea coast, the complexion of the inhabitants is observed to darken through Upper Egypt and in Abyssynia. Of this country it is interesting to remark that it still retains the Christian faith as delivered to it in the remotest times of the Church.

Variations impressed on the African races.

The negro zone.

The portrait of an Abyssinian, *Fig.* 276, from M. d'Abbadie, shows

Fig. 276.

Abyssinian.

Fig. 277.

Native of Madagascar.

an admixture of the Arab lineaments, though there is no reason to suppose

that this is due to the admixture of Arab blood. Of the two classes of Abyssinians, those who inhabit the more southerly parts have a countenance much more approaching to the negro. They are, indeed, an intrusive race, who conquered in more recent times the regions in which they are settled. It is said that the Amharic, the language of the true Abyssinians, is singularly analogous to the Hebrew.

As resembling the Abyssinians in many respects, though on the opposite side of the equator, may be mentioned the natives of Madagascar, *Fig.* 277, p. 577. Presenting, in some particulars, the traces of Arab influence, it has nevertheless been inferred, partly from their language and partly from their features, that the most numerous class is of Malay origin. Though among the inferior tribes there are some which are black, the complexion of this is olive, and the hair is not woolly, though it curls.

Evidences from similarity of countenance and language.

It should be constantly borne in mind that the resemblance of features is no proof of a community of origin. The influence of climate and of manner of life is so great that in a due period of time the most diverse tribes will show similar lineaments. Analogy in the structure of languages and identity in vocabulary is much better evidence, though even this must be received with caution. In reference to this, it has been very significantly remarked that birds of the same kind sing the same notes in all countries, even though under such circumstances as to exclude the possibility of their having been taught by their parents.

Fig. 278.

Native of Mozambique.

The annexed figure, 278, is given by Dr. Prichard as a specimen of the natives of Mozambique. The expression is undoubtedly much superior to that prevailing on the West African coast. Of some of these tribes it is said that the hair is not woolly, but merely frizzled. It grows long, and hangs in slender curls.

Amelioration of the negro type to the east.

Examining the zone designated as negro land, we find that the negro character of its inhabitants is not in all parts developed with equal intensity. The maximum is shown in the Guinea countries, and from thence across the continent to the east the physiognomy improves. The negro characteristics may be specified as intense blackness of the skin, woolly hair, thick lips, gaping nostrils,

Fig. 279.

Negro of Guinea.

and a prognathous skull. But the negro aspect is not limited to the African continent; it is prolonged or projected through the Indian into the Pacific Ocean, north and south of the equator, in a zone of many degrees. Sumatra, Borneo, Celebes, New Guinea, and part of Australia, lie in this zone. In these various countries, one or another of the characteristics we have mentioned predominate, in part through the influence of climate, and in part through admixture of blood. In some of these people the hair is not woolly; in some, the lips are thin, and the nose projecting; in some, the form of the skull indicates a great superiority over the West African tribes. But, whatever these modifications may be, the black races of the Pacific present in their general appearance so predominating a negro aspect that they have by all travelers been classed with that tribe. Of one of these nations, Dampier, the early navigator, speaks as "shock, curl-pated, New Guinea negroes." The portrait, *Fig.* 280, from Choris's Voyage Pittoresque, of a girl of the island of Luzon, one of the Philippines, may illustrate this remark; for, though the form of the head shows a very great advance upon that of the Guinea negro, the facial angle, respecting which more will shortly be said, being much larger, and the relative size of the brain therefore increased, the countenance is essentially that of tropical Africa.

Fig. 280.

Philippine negro.

Variations impressed on the Pacific race.

The projection of the African type into the Pacific is crossed at a certain point by a like projection of the dark Asiatic type, and in the region of this intersection or commingling we find the most degraded specimens of humanity.

Amelioration of the Pelagian type to the east.

From these regions, as we pass eastwardly toward the American continent, the improvement becomes very striking; thus the natives of the Society Islands, though living within the tropic, are of a clear olive or brunette. In the opinion of

some, if it were not for a slight thickness of the lips and spreading of the nostrils, the countenance would be European. The men are described as "tall, strong, well-limbed, and finely shaped." Many of the children have flaxen hair; and sailors, who are generally competent judges of such matters, universally yield a tribute of admiration to the prettiness of the women. Captain Bligh attributed the mutiny in his ship to that interesting cause.

We may next consider variations in the form of the skeleton.

Comparison of skeletons.

Here, more particularly in the classification of the forms of skulls, I adopt the division introduced by Dr. Prichard, from whose work, above alluded to, the following passages are extracted:

The leg.

"In all other races, compared with Europeans, the limbs are more crooked and badly formed. In the negro the bones of the leg are bent outward. Soemmering and Lawrence have observed that the tibia and fibula in the negro are more convex in front than in Europeans; the calves of the legs are very high, so as to encroach upon the hams; the feet and hands, but particularly the former, are flat; the os calcis, instead of being arched, is continued nearly in a straight line with the other bones of the foot, which is remarkably broad."

The arm.

"It was observed by White, and has been generally believed, that the length of the forearm is so much greater in the negro than in the European as to constitute a real approximation to the character of the ape. Facts, however, prove but a very slight difference, and by no means greater than the varieties which are every day to be observed on comparing many individuals of any race or nation. On the other hand, the difference between adult apes and men in the length of the extremities is so great as to render all such comparisons very remote, and of very doubtful importance with respect to any ulterior conclusion. According to Mr. Owen, the arms of the orang reach to the heel, or at least to the ankle-joint, while in the chimpanzee, or troglodyte, they extend below the knee-joint. This is a most decided and widely-marked difference between the most anthropoid apes and the uncultivated races of men. Yet even the slightest approach to the former shape would be a curious circumstance; if it could be fully established, it would tend, with other facts, to imply that the savage races of mankind have somewhat more of the animal, even in their physical conformation, than the more cultivated races, or those whose improvement by civilization may be dated from a very remote era in the history of the world."

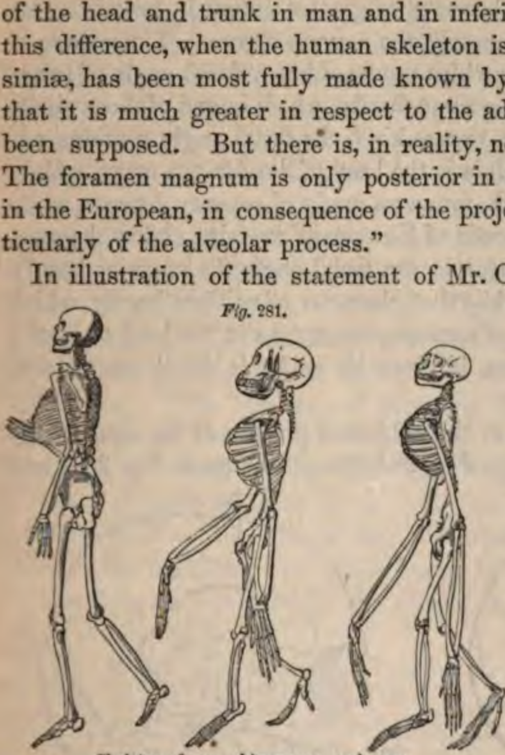
The foramen magnum of the skull.

"It has been a general opinion, since the time of Soemmering, that the head of the negro is placed so much farther backward on the vertebral column as to occasion a material difference in the figure of the whole body. It was observed by Daubenton that the foramen magnum is placed in quadrupeds behind the centre

of gravity, whence an important difference arises in the relative position of the head and trunk in man and in inferior animals. The extent of this difference, when the human skeleton is compared with that of the simiæ, has been most fully made known by Mr. Owen, who has shown that it is much greater in respect to the adult ape than it has hitherto been supposed. But there is, in reality, no difference in human races. The foramen magnum is only posterior in the negro skull to its place in the European, in consequence of the projection of the upper jaw, particularly of the alveolar process."

In illustration of the statement of Mr. Owen respecting the relative length of the arm in man and in the more anthropoid apes, I give the annexed photograph, *Fig.* 281, of the human skeleton and those of the chimpanzee and orang. Of the chimpanzee it should be observed that the specimen was young. They are all brought nearly to the same size by adjusting the distances at which they were taken. The human skeleton was that of a man more than six feet in height.

Fig. 281.



Skeleton of man, chimpanzee, and orang.

Four modes of examining the skull.

There are four different views from which an examination of the skull of man and animals may be made: 1st. The lateral; 2d. The vertical; 3d. The basilar; 4th. The front.

1st. The lateral view, or Camper's method, is thus described by the anatomist who introduced it, and whose name it bears.

The lateral view, or Camper's method.

"The basis on which a distinction of nations is founded may be displayed by two straight lines, one of which is to be drawn through the meatus auditorius to the base of the nose, and the other touching the prominent centre of the forehead, and falling thence on the most advancing part of the upper jaw-bone, the head being viewed in profile. In the angle produced by these two lines may be said to consist not only the distinctions between the skulls of the several species of animals, but also those which are found to exist between different nations; and it might be concluded that Nature has availed herself, at the same time, of this angle to mark out the diversities of the animal kingdom, and to establish a sort of scale from the inferior tribes up to the most beautiful forms which are found in the human

species. Thus it will be found that the heads of birds display the smallest angle, and that it always becomes of greater extent in proportion as the animal approaches more nearly the human figure. Thus there is one species of the ape tribe in which the head has a facial angle of forty-two degrees; in another, of the same family, which is one of those simiæ most approximating in figure to mankind, the facial angle contains exactly fifty degrees. Next to this is the head of the African negro, which, as well as that of the Kalmuck, forms an angle of seventy degrees, while the angle discovered in the heads of Europeans contains eighty degrees. On this difference of ten degrees in the facial angle the superior beauty of the European depends; while that character of sublime beauty, which is so striking in some works of ancient statuary, as in the head of Apollo and in the Medusa of Sisocles, is given by an angle which amounts to one hundred degrees."

As illustrations of this view, the subjoined profiles of the skull of the European, *Fig.* 282, the negro, *Fig.* 283, the chimpanzee, *Fig.* 284, and

Fig. 282.

European.

Fig. 283.

Negro.

the orang, *Fig.* 285, are given. Of the latter, which, of apes, are among

Fig. 284.

Chimpanzee.

Fig. 285.

Orang.

those most closely approaching to man, the chimpanzee is a native of tropical Africa, and the orang of the Indian Archipelago.

2d. The vertical view, or Blumenbach's method.

"Blumenbach gives the following account of the way of describing heads, which, he says, is the result of his own observations in a long and constant study of his collections of the skulls of different nations: He remarks that the comparison of the breadth of the head, particularly of the vertex, points out the principal and most strongly-marked differences in the general configuration of the cranium. He adds that the whole cranium is susceptible of so many varieties in its form, the parts which contribute more or less to determine the national character displaying such different proportions and directions, that it is impossible to subject all these diversities to the measurement of any lines or angles. In comparing and arranging skulls according to the varieties in their shape, it is preferable to survey them in that method which presents at one view the greatest number of characteristic peculiarities. 'The best way of obtaining this end is to place a series of skulls with the cheek-bones on the same horizontal line, resting on the lower jaws, and then, viewing them from behind, and fixing the eye on the vertex of each, to mark all the varieties in the shape of parts that contribute most to the national character, whether they consist in the direction of the maxillary and malar bones, in the breadth or narrowness of the oval figure presented by the vertex, or in the flattened or vaulted form of the frontal bone.'"

The vertical view, or Blumenbach's method.

By this means of comparison Blumenbach obtains a division of skulls into three classes, the Caucasian, Mongol, and Negro. They are represented in *Fig.* 286, *Fig.* 287, *Fig.* 288, and Dr. Prichard has added to these figures *Fig.* 289, the artificially elongated skull of an ancient Peruvian, from the burial-places of Titicaca.

Fig. 286.

Caucasian.

Fig. 287.

Mongol.

3. The basilar view, or Owen's method.

"No single view of the skull determines so much in regard to its general configuration as that of the basis. The importance of this manner of examining the bony structure of the head has been demonstrated in the fullest manner by Mr. Owen,

The basilar view, or Owen's method.

Fig. 288.

Negro.

Fig. 289.

Titicacan.

in his excellent memoir on the structure of the orang and chimpanzee. The relative proportions and extent, and the peculiarities of formation of the different parts of the cranium, are more fully discovered by this mode of comparison, which has hitherto been much neglected, than by any other method."

Fig. 290.

Human skull.

Fig. 291.

Skull of orang.

"It may be observed, in this view of the cranium, that the antero-posterior diameter of the basis of the skull is in the orang very much larger than in man. The most striking circumstance which displays this difference is the situation occupied by the zygomatic arch in the plane of the basis of the skull. In all races of men, and even in human idiots, the entire zygoma is included in the anterior half of the basis cranii; in the head of the adult troglodyte, or chimpanzee, as well as in that of the satyr, or orang, the zygoma is situated in the middle region of the skull, and in the basis occupies just one third part of the entire length of its diameter. Posterior to the zygomata, the petrous portions have, in the simiæ, a larger development in the antero-posterior direction.

Another most remarkable character, in respect to which those anatomists have been greatly deceived who compared only young troglodytes with man, is the great occipital foramen, a feature most important as to the general character of structure and to the habits of the whole being. This foramen, in the human head, is very near the middle of the basis of the skull, or, rather, it is situated immediately behind the middle transverse diameter, while in the adult chimpanzee it is placed in the middle of the posterior third of the basis cranii. A third characteristic in the ape is the greater size and development of the bony palate, in consequence of which the teeth are much larger and more spread, and want that continuity which is, generally speaking, a characteristic of man; and intervals between the laniary, cutting, and bicuspid teeth admit, as in the lower tribes of animals, the apices of teeth belonging to the opposite jaws. Fourthly, the basis of the skull is flat, owing to the want of that downward development of the brain, and of the bony case connected with the greater dimension which the cerebral organ acquires in the human being compared with the lower tribes."

4. The front view, or Prichard's method.

The front view, or Prichard's method.

"Neither the facial angle of Camper, nor the method of viewing the skull proposed by Blumenbach, affords a satisfactory display of the characteristics of the pyramidal or lozenge-faced skull."

"In *Fig.* 292, which is the drawing of the skull of an Esquimaux, the lines drawn from the zygomatic arch, touching the temples, meeting over the forehead, form with the basis a triangular figure. These two lines in well-formed European heads are parallel, the forehead being very much broader than in the heads of Esquimaux, and other races whose skulls belong to the same great division of human crania, among whom are the Mongolians, and other nomadic nations of Northern Asia. The most striking characteristic of these skulls is the great lateral or outward projection of the zygomatic arch. The cheek-bones, rising from under the middle of the orbit, do not project forward and downward under the eyes, as in the prognathous skull of the negro, but take a direction laterally or outward, and turn backward to meet a corresponding projection of the process of the temporal bone, and form with it a large, rounded sweep or segment of a circle. The orbits are large and deep. The upper part of the face being remarkably plane or flat, the nose flat, and the nasal bones, as well as the

Fig. 292.

Esquimaux.

space between the eyebrows, nearly on the same plane with the cheek-bones, the triangular space described by the lines (drawn on the wood-cut) may be compared to one of the faces of a pyramid. The whole face, instead of an oval form, as in most Europeans and many Africans, is of a lozenge shape."

"Another characteristic in most of the pyramidal skulls, or, rather, in the form of the face to which this configuration of the skull gives rise, is the apparently angular position of the aperture of the eyelids. There is no want of parallelism in the orbits, or, rather, of coincidence in the transverse sections of the orbital cavities. The obliquity consists in the structure of the lids themselves; the skin, being tightly drawn over the large protuberance of the malar bone, under the outer angle of the eye, and at the inner extremity smoothly extended over the lower nasal bones, while the bridge of the nose is scarcely elevated above the plane of the suborbital spaces, gives to the eye the appearance of being placed with the inner angle downward."

"The oval or elliptical form is that of Europeans, and the southern Asiatics who resemble them; the zygomatic bones and the jaws being less protuberant, the entire outline of the head, viewed from above, has no projecting angular parts, and is defined by an oval circumference. But in that oval figure, or rather ellipse, the two diameters vary considerably in proportion; in other words, some nations have rounder, others more elongated heads. The shape of the brain, and of the skull at its basis, is in the rounder heads more like that of the pyramidal skull, or the cranium of the northern Asiatics; in the narrower heads it approaches the figure of the elongated, or negro head."

We may therefore conveniently classify skulls in three divisions:

Classification of skulls.

1st. The prognathous, which is represented in *Fig.* 293, being the skull of a negro of very forbidding aspect. This form is marked by a forward projection of the jaws, the brain being therefore, as it were, thrown backward as respects the face, the forehead being more horizontal and low.

2d. The pyramidal, *Fig.* 292, which gives rise, as has been stated above, to the lozenge-shaped face.

3d. The elliptical or oval, which, viewed from above, has an oval contour without projecting parts, and in the profile shows a large facial angle, as in the French skull, *Fig.* 294.

Connection of the shape of the skull and manner of life.

These forms of skull seem to be connected very closely with habits of life: the prognathous with the savage state, or that of hunting; the pyramidal with a wandering pastoral life; and the elliptical with that of civilization.

With respect to the form of the pelvis in different nations, the variations are by no means so significant as in the case of the cranium, inas-

Fig. 293.

Negro.

Fig. 294.

French.

much as they are of indiscriminate occurrence. It may perhaps be maintained in a general way, that in the less advanced tribes, as in the female Hottentot, there is an approximation to the form exhibited by the simiæ, the iliac bones being more vertical, and the whole structure characterized by its length and narrowness. Professor Weber, who has examined this subject with care, concludes that no particular figure of the pelvis is a characteristic of any one race.

The pelvis.

The remarks which have been made respecting variations of complexion, as exhibited in different climates, might almost be repeated as respects variations of the form of the skull, originating in difference of physical circumstances; for as the complexion varies in different temperatures, so does the figure of the skull in different social conditions. The elliptical skull, which beyond all doubt is that which belongs to man in his most civilized state, may be deteriorated and degraded even to the lowest prognathous form. Want and squalid misery will produce this result. Ignorance, mere animal life, social degradation, lead to its approach in varied degrees. Even in the large European cities we recognize the incipient stages of it in those classes who follow a precarious life—the projecting jaw, the retreating forehead, the mouth habitually open, or the lips parted so as to show the teeth. Mr. Thackrah, in his work on the Effects of Arts, Trades, etc., on Health and Longevity, says, "I stood in Oxford Road, Manchester, and observed the stream of operatives as they left the mills at twelve o'clock. The children were almost universally ill-looking, small, sickly, barefoot, and ill-clad. Many *appeared* to be no older than seven. The men, generally from sixteen to twenty-four, and none aged, were almost as pallid and thin as the children. The women were the most respectable in appearance, but I saw no fresh, fine-looking individuals among them. Here I saw, or thought I saw, a degenerate race—human beings stunted, enfeebled, depraved." Under the opposite circumstances, where life is maintained in indolence

The physical causes of variation in the skull.

Its degradation by want.

and plenty, the converse effects may take place. Of this, perhaps the most striking illustration is that pointed out by Dr. Prichard of the loss of the pyramidal form of skull by the European Turks, a form which appertained to their Asiatic ancestors, and the assumption of the elliptical, the skull not of a wandering, but of a stationary and civilized race. Nor has this transmutation taken place in them, in the short period since they made their European conquest, because of the influence exercised by the Circassian and Georgian women introduced into their harems, for this has been upon too small a scale to produce such a general result, and is a luxury which can only be indulged in by the wealthier classes.

Its rectification by luxury.

As a descent is made to the skull of the prognathous form, the countenance loses those features which we regard as being beautiful, and assumes a baser cast. When it has reached the limit in that direction, it is actually hideous, recalling at once the detestable aspect of the ape. In this state, in the tropical climates, the lips are thick, the hair woolly, the nostrils gaping. The intellectual powers are correspondingly depressed; the dullness of the eye, its porcelain-like sclerotic contrasting with the blackness of the skin, is in correspondence with the low and degraded mental power. On the contrary, when the passage is made toward the elliptical form, the countenance becomes more beautiful and interesting, capable of expressing the most refined mental emotions. The eyes, in an indescribable but significant manner, manifest the exalted powers of the mind, and the lips are composed or compressed.

Contrast between the prognathous and elliptical skulls.

If I am not mistaken, darkness of the skin and a prognathous form of skull may be dependent in the dark tribes on the same circumstance. Functionally the liver is in connection with the calorifacient apparatus, its secretion, the bile, as shown in Chapter XI., coinciding in habitudes with a hydrocarbon. Much of it is therefore reabsorbed, and eventually devoted for the support of a high temperature. But, besides this combustible material, the bile likewise contains a coloring matter, which is in all respects an effete body, and useless to the system. This pigment is derived from the blood-discs, or, rather, from their hæmatin, as is proved by the fact that it occurs in the meconium of the new-born infant, and likewise, like hæmatin, it is rich in iron. Its source is, therefore, not immediately from the food. To remove this useless material is thus one of the primary functions of the liver.

Mode in which heat produces a dark complexion.

Now there is no organ which is more quickly disturbed in its duty by a high temperature than the liver. Whether such a high temperature produces its effect through a disturbance of the action of the lungs, or through an impression on the skin, is

Influence of the action of the liver on the complexion.

quite immaterial. If the organ be in any manner enfeebled in its duty, and no other avenue is open through which the degenerating hæmatin may escape, it must accumulate in the circulation, and be deposited here and there in suitable places. Under such circumstances, there arises a tendency for its accumulation in a temporary manner in the lower and more spherical cells of the cuticle, from which it is removed by their gradual exuviation and destruction as they become superficial. The temporary deposit of the coloring matter in this situation imparts to the skin a shade more or less deep. It may amount to a perfect blackness; for the origin of the black pigment of the negro is the same as that of the black pigment of the eye in all races, and the predominating percentage of iron it presents plainly betrays that it arises from a degenerating hæmatin, in which the same metal abounds.

The color of the skin derived from the hæmatin of the blood.

I believe, therefore, that the coloration of the skin, whatever the particular tint may be, tawny-yellow, olive-red, or black, is connected with the manner in which the liver is discharging its function. That deposits of black pigment can normally arise in the way of a true secretion by cell action is satisfactorily proved by their occurrence in angular and ramified patches in the skin of such animals as the frog; and that hæmatin, in its degeneration, may give rise to many different tints, is substantiated by the colors exhibited by ecchymoses.

It is not to be forgotten that coloration of the skin, though apparently persistent, is tending continually to a removal, because of the oxidation which is taking place as the pigment cells approach the surface of the cuticle in their process of desquamation; but as this goes on, new cells and new pigment are perpetually forming beneath, to undergo destruction in their turn. Under this point of view, the complexion of the skin is an index of the energy with which that tissue is addressing itself for the removal of metamorphosing hæmatin. In accomplishing this removal, the liver, in the fair races of mankind, exerts a sufficient activity; but in hot climates, the habitation of the black races, either through a diminished power of that gland, or because of an increased production of effete pigment, the skin has to lend its aid, and the degree to which it does this is betrayed by the depth of its hue.

Constant removal of the color of the skin.

Having thus traced the coloration of the skin to existing peculiarities of hepatic action, I may repeat the remark already made, that it is not improbable that, in the most degraded negro type, the prognathous form of the skull may be attributed to the same cause.

Influence of the action of the liver on the form of the skull.

Not that this alone is always the cause, for a prognathous skull can by degrees arise, as we have seen, in any race, even the white, from a

variety of causes, such as misery, want, or an oppressed social state. It is, however, on all hands admitted that nothing so quickly disturbs the brain in its action as functional disturbance of the liver. If, through a partial failure in the operation of that great gland, the products which it should normally secrete begin to accumulate in the blood, or have to seek new channels for their escape, the vigor of the intellect is at once impaired. It is with the brain as it is with any other organ, a decline in its activity is soon followed by a deterioration or diminution of its structure, and we must not forget that it is not the brain which accommodates itself to the capacity of the skull, but the skull which accommodates itself to the shape and size of the brain. Whatever the causes may be, and of course they are very numerous, which tend to lessen the entire cerebral mass, or by inequality in their effect produce the development of one part with the contemporaneous diminution of another, they will inevitably give rise to a modification in the figure of the skull; and observation, as well as phrenological considerations, would cause us to anticipate that, if the effect takes place in such a way as to involve the higher powers of intellection, the skull, answering in its change thereto, will assume the prognathous cast.

Hereditary transmission of variations.

From what I have said respecting the relationship of different nations of men, it will be gathered that the peculiarities on which we have been dwelling, the complexion and form of the skull, as dependent upon hepatic action, are capable of hereditary transmission; for such a modified glandular action, in whatever manner it may have been occasioned, can be propagated in that way.

Base form of skull arising from low temperature.

In these remarks it will be perceived that I have mainly had in view that degradation from the more perfect standard of man which is encountered in hot climates, and which finds its expression in a blackness of the skin and a base form of the skull. But there is likewise a white degraded form. It is that which we meet in the highest latitudes, and it is therefore dependent upon climate, that is to say, temperature. Here no such tax is thrown upon the skin as is the case in the torrid zone, but here the intellectual powers are greatly enfeebled, if for no other reason, at least because of the hardships under which life must be maintained. It is not, therefore, in very high or very low latitudes that we should expect to find man in his best estate, and this is corroborated by the history of all races. It is true that, by the artificial control which we have obtained over temperature by the aid of clothing and improved modes of shelter, we have, in some degree, withdrawn ourselves from the absolute dominion of climate; but, putting these disturbances of civilization aside, and looking only to our natural state, we shall be constrained to admit that the man of maximum intellectual capacity is of a faint brown hue. Nor was it through any acci-

dental circumstance, but because of physiological conditions, that civilization arose in Egypt and in the Mesopotamian countries. It was for a like physiological reason that it spread next through the nations on the north shore of the Mediterranean, and never spontaneously originated in Arctic Europe or Tropical Africa.

Maximum of intellect among the faint brown races.

Moreover, it must be observed how forcibly the doctrine here urged of the passage of man from one complexion to another, and through successively different forms of skull in the course of ages, is illustrated by the singular circumstance to which attention has of late years been directed, of the gradual disappearance of the red-haired and blue-eyed men from Europe. Less than two thousand years ago, the Roman authors bear their concurrent testimony to the fact that the inhabitants of Britain, Gaul, and a large portion of Germany were of that kind. But no one would accept such a description as correct in our times. By some writers, who have not taken enlarged physiological views, this curious circumstance has been attempted to be explained on the hypothesis of a more prolific power of the brown or black haired and darker man. That this is correct not a shadow of evidence can be offered. The supplanting of the red by the black haired man is neither on account of any insidious or involuntary extermination, nor because of the numerical pressure alluded to. The true reason is that the red-haired man has himself been slowly changing to get into correspondence with the conditions that have been introduced through the gradual spread of civilization—conditions of a purely physical kind, and with which the darker man was more nearly in unison; for though it might be shown that the climate of Europe, by reason of the removal of forests, and other causes, chiefly agricultural in their nature, has undergone a change, this is nothing compared with the changes that have been accomplished in domestic economy by better clothing, and more comfortable lodging and food, and these are parallel to actual changes in climate. What a contrast between the starved, naked, and almost houseless peasant-savages of the times of Cæsar, and the well-fed, well-clothed, and well-housed agricultural laborers or manufacturing operatives of ours, who, though they may be living in the same geographical region, are literally in a warmer and more genial climate—a climate with which man is only in correspondence when his skin is of a darker shade, and his hair of a brown or black color!

Disappearance of the red-haired and blue-eyed people in Europe.

Cause of this apparent disappearance.

From these investigations of the anatomical peculiarities of the nations of men, we may turn to those of a mental kind, which, indeed, are derivatives thereof. Doubtless the intellectual qualities are manifested in the expression of the countenance and in the capacity and form of the skull.

Of the intellectual qualities of nations.

Considering, for the sake of convenience, groups of nations as they

are distributed geographically, though, as we have seen, this is a division which has no philosophical foundation, we may proceed to an examination of the psychical state of the European and Asiatic, whose history furnishes us abundant materials for this purpose. The black nations of Africa and the red tribes of America, from the imperfect advances they have made toward civilization, can supply but few facts for such an investigation.

Synthetical mind of the Asiatic; analytical mind of the European.

We can not read the histories of Europe and Asia—we can not examine the present condition of those continents, without coming to the conclusion that the people inhabiting them possess a different mental constitution. After what has been said respecting the influence of physical circumstances on the organization of man, it is unnecessary for us to inquire here in what that difference has originated. It is, perhaps, most significantly expressed if we say that the mind of the Asiatic is essentially synthetic, that of the European analytic. The former is the creator of systems of theology, law, science, some of which have endured for thousands of years, and have been adopted by a large portion of the human race. The latter pursues his course in a way less grand, but which, since it has a better ascertained foundation, leads to more certain, and, in the course of centuries, will show more powerful, widespread, and equally lasting results. The intellectual peculiarity of the Asiatic has been attended with the advantage of producing an almost definite social state. In Asia the customs remain invariable; every thing is in a state, as we might term it, of stagnation, or, as they consider it, of repose. On the other hand, the analytical tendency of the European has led to the intellectual and political anarchy of our times, when fundamental doctrines of every kind are called in question, and scarcely two men can be found whose views on religious, political, and social questions coincide. In Asia there are no questions, but only affirmations. Europe, except when the Church for a thousand years enforced the Asiatic system, has ever been prone to ask questions. Since the fourteenth century, when she returned to this propensity, she has been passing through a chaos of doubt in the innumerable answers she receives.

Necessity of the Asiatic to European civilization.

With an intellect of this analytical kind, it may be doubtful whether the European could ever have spontaneously entered on the career of civilization. The contact of the Asiatic was essential to him, as giving him the material on which to work. Nor was it of importance whether the basis from which he thus started, and the additions which, from time to time, he has received, were true or false; they furnished him with the essential condition that was wanting. The dissector must have his subject. The history of Europe, whether as regards philosophical, religious, or political affairs, bears the impress

of the analytical mind of the white man. In Asia, on all these points they tend to the homogeneous. In Europe, every day makes us more and more heterogeneous.

Thus compared with that of the Asiatic, it can not be denied that the mind of the European is of the higher order. Moreover, though our moral qualities are not equal to our intellectual, the manner in which we act in the conditions in which we are placed asserts our superiority even in that regard. The instances are many in which we do not dare to carry our convictions into execution, and each of these illustrates the inequality here set forth. To be content with the chances of things, to suffer the events of life uncomplainingly, is surely not so worthy a character as to demand a reason, and to accept the consequences of resistance.

Comparison of the Asiatic and European intellect.

The intellectual superiority of the European over the Asiatic is strikingly illustrated by their relative power over the African, who is confessedly, in this respect, beneath them both. To go no farther back than the last ten centuries, both have, in their special way, exerted their influence. Here and there, on the outskirts of that great continent, the European has made a faint, but, at the best, only a transitory impression: the Asiatic has pervaded it through and through. Of the promising churches, which, in the early days of Christianity, fringed the northern coast, scarce any vestige now remains; the faith of Arabia has not only supplanted them, but is spreading even toward the Cape of Good Hope, and this, as it would appear, spontaneously. On the other hand, the European, with that universal charity which is his noblest attribute, has spared no exertions and no expense to diffuse the blessings which have been conferred by Providence upon him; and yet it would seem to be in vain, though enforced by the great example of his civilization and power. In this we see the affinity of the mind of Africa with that of Asia, of which it is an exaggeration, and its incongruity with that of Europe. It can not, in its present state, appreciate our manner of thinking; it can not embrace our conceptions of truth, but delivers itself unresistingly to the dogmas of the East, with all their errors of faith and all their imperfections of polity.

Their respective influence on Africa.

Since I have been drawn into a psychical comparison of the Asiatic and European in the foregoing particulars, it may not be amiss to consider the two races in another important respect, the condition of their females. In the barbarous state, the woman is the slave of the man; the Mohammedan makes her his toy, the European his companion. The avarice of the former for beauty is replaced in the latter by an avarice for wealth. The treasures of the one are placed in a harem; those of the other are perhaps invested in the public stocks.

Position of women in Asia and in Europe.

The natural position of the female sex in this respect is indicated at once by the relation of numbers. In Europe, for every 106 male births there are 100 female, and as the sex of offspring is influenced by the relative ages of the parents, the older parent giving a tendency to its own sex, we may reasonably suppose that in the infants born of polygamy the males will preponderate, reversing the result which is observed in the great cities of Western Europe, in which the ratio of female births rises above its true mean by nearly four per cent. when those births are illegitimate. In that term of the market, four per cent., what a volume of information is here conveyed! It tells us that the European female does not fall at once; that there intervene years of resistance to temptation, a struggle of virtue against penury and distress, but it also reveals the precocious wickedness of man!

Considering, therefore, the near equality of male and female births, we may truly assert that monogamy is the proper condition of our species, and that, apart from its social evils and criminality, polygamy is an unnatural state. I shall pass, as unworthy of notice, the assertion of those who, in this Christian country, practice so shameful a vice, that we might as well divide the number of square acres on the face of the globe by the number of its inhabitants, and declare it to be immoral in any one to possess a larger estate than corresponds to the quotient thereof. Acknowledging the natural depravity of the human heart, I accept with humiliation the rebuke that the most enlightened communities exhibit in these respects a deplorable spectacle, and that the vices of the Mohammedan harems find their full counterpoise in the general, the awful, and, in many places, the legalized prostitution of Christian cities.

Effects of polygamy and monogamy.

Europe has adopted as the fundamental basis of its religious system the grand Asiatic truth of the unity of God, but in its family system it has rejected the immemorial and widespread Asiatic practice of polygamy. That circumstance has made it what it is. The monogamous habit has tended to draw the family tie more firmly, and has led to the accumulation and transmission of wealth from generation to generation in the same house. With this have arisen a liability to concentration of power in castes, and the use of surnames which have perpetuated family interests and family pride. In Europe the career of improvement is in the society; in Asia it is in the individual; the unknown, starving, illiterate, but strong-willed soldier of to-day is the Pasha, the Caliph, the Emperor to-morrow. The castes of India form but a trifling exception to the fact that, in the midst of a universal despotism, the primest democratic element is concealed, for the career is open to talent. Through this, Asia has asserted her superiority again and again. Europe has never produced a great lawgiver; Asia has produced many. Generations of

The respective progress of Asia and Europe.

three hundred millions of men have followed the maxims of Confucius for two thousand years, three hundred millions are the followers of Mohammed. The faiths which govern the daily life of two thirds of the human race may well be an awful spectacle to us—the more awful because we know that they are a delusion. The only approach to these great results in the Western Continent is in the supremacy of the Italian Church; but Rome owed the origin of her system to Asiatic missionaries; nor was it the completed work of the hand of one man, it was the offspring of centuries, the joint issue of a long line of illustrious sacerdotal kings. In military life the highest qualities shine forth. If the talent for command and the capacity of a statesman are to be measured by the grandeur of undertakings and their success, it still remains for Europe to produce a soldier the equal of Genghis Khan, and a king like Tamerlane. These great captains held almost all Asia in their iron grasp. The opinions we commonly hold respecting these illustrious men have come to us through perverted channels. Such prodigious successes as theirs imply the highest intellectual powers. Their true character appears when we compare them with their European contemporaries. At the same time that Charles VII. of France was mystifying his people with the imposture of Joan of Arc, and Henry VI. of England was engaged in the burning of necromancers who had attempted his life by melting an enchanted wax image before the fire, Ulug Beg, the grandson of Tamerlane, was determining with precision the latitude of Samarcand, his capital, with a mural quadrant of 180 feet radius, and making a catalogue of the stars from his own observations, which more than 200 years subsequently was printed at the University of Oxford.

Contributions of the Asiatic to European civilization.

If the European wishes to know how much he owes to the Asiatic, he has only to cast a glance at an hour of his daily life. The clock which summons him from his bed in the morning was the invention of the East, as were also clepsydras and sun-dials. The prayer for his daily bread which he has said from his infancy first rose from the side of a Syrian mountain. The linens and cottons with which he clothes himself, though they may be very fine, are inferior to those which have been made time immemorial in the looms of India. The silk was stolen by some missionaries, for his benefit, from China. He could buy better steel than that with which he shaves himself in the old city of Damascus, where it was first invented. The coffee he expects at breakfast was first grown by the Arabians, and the natives of Upper India prepared the sugar with which he sweetens it, a schoolboy can tell the meaning of the Sanscrit words sacchara canda. If his tastes are light, and he prefers tea, the virtues of that excellent leaf were first pointed out by the industrious Chinese. They also taught him how to make and use the cup and saucer in which to serve

it. His breakfast-tray was lacquered in Japan. There is a tradition that leavened bread was first made of the waters of the Ganges. The egg he is breaking was laid by a fowl whose ancestors were domesticated by the Malaccans, unless she may have been, though that will not alter the case, a modern Shanghai. If there are preserves and fruits on his board, let him remember with thankfulness that Persia first gave him the cherry, the peach, the plum. If in any of those delicate preparations he detects the flavor of alcohol, let it remind him that that substance was first distilled by the Arabians, who have set him the praiseworthy example, which it will be for his benefit to follow, of abstaining from its use. When he talks about coffee and alcohol, he is using Arabic words. A thousand years before it had occurred to him to enact laws of restriction on the use of intoxicating drinks, the Prophet of Mecca had accomplished the same object, and, what is more to the purpose, has compelled, to this day, all Asia and Africa to obey it. We gratify our taste for personal ornament in the way the Orientals have taught us, with pearls, rubies, sapphires, diamonds. Of public amusements it is the same: the most magnificent fireworks are still to be seen in India and China; and as regards the pastimes of private life, Europe has produced no invention which can rival the game of chess. We have no hydraulic constructions as great as the Chinese canal—no fortifications as extensive as the Chinese wall; we have no artesian wells that can at all approach in depth some of theirs; we have not yet resorted to the practice of obtaining coal-gas from the interior of the earth: they have borings for that purpose more than 3000 feet deep.

Asiatic contributions in art.

Similar observations may be made if we examine the Asiatic contributions to science. While the learned of Europe were forbidding, as a heresy, the doctrine of the globular figure of the earth, the Caliph Al Maimon was measuring the length of a degree along the shore of the Red Sea. He and his successors repeatedly determined the obliquity of the ecliptic. A Saracen constructed the first table of sines, another explained the nature of twilight, and showed the importance of allowing for atmospheric refraction in astronomical observations. Algebra itself was invented and brought into Europe by the Mohammedans, who gave it the name it bears. The same may be said of chemistry. It is needless to pursue these statements, for whoever will take the trouble to look into the history of any branch of science existing in the seventeenth century will find how deep are its obligations to Asia. I shall therefore add but one fact more, the invention of the figures of arithmetic, which in reality gave birth to that science, and laid knowledge and commerce equally under obligations. From its simplicity, beauty, and universality, this invention alone is enough to command the gratitude of the human race. The manner of using the cipher and

Asiatic contributions in science.

placing the figures is one of the happiest suggestions of the genius of man.

I shall not set in contrast with these statements a catalogue of the contributions of the European. We know our own doings well enough; but such facts as the preceding may serve to remind us that the European is no more justified in ignoring the obligations he is under to the Asiatic than the Asiatic is justified in regarding him as a barbarian. In the advance of our common humanity, both have taken and still are taking their share. The European has brought to the new continent he discovered his religion, his laws, his literature, his science, and it may be a profitable subject of reflection to him that under them the Indian is dying away. The Asiatic has likewise carried the Koran into Africa. Our prejudices and education ought not to conceal from us that there must surely be some adaptedness, even if it be in a sensual respect, between its doctrines and the ideas of many climates, many nations, many colors. The light of the Arabian crescent shines on all countries from the Gulf of Guinea to the Chinese wall. In those pestilential and sun-burnt forests under the equinoctial line, cities are springing up with their ten, their twenty, their fifty thousand inhabitants. That implies subordination, law, civilization. It may be that this is not a course of events which would have been chosen by the French on the north, with their military colonies; the English on the south, with their commercial establishments; the Americans on the west, with their political institutions; but it is the course of Providence. Let us be thankful if the African is rescued from the abyss of barbarism, and brought to a knowledge of our higher morality and holier religion, as brought he will be at last, even though it be by the hand of the Prophet.

The spread of Mohammedanism in Africa.

In the following chapter I shall have some remarks to make respecting the manner in which the civilization of Europe was accomplished, and shall offer reasons for supposing that its essential condition was a physiological change in the inhabitants. Without troubling the reader with details, I may here incidentally observe that the spread of Mohammedanism in Africa is altogether owing to its having been introduced in the right direction. It appears to me hopeless to attempt the amelioration of that continent from its western shore. Whatever is done must be done from the East. In power of intellect, and in a disposition to appreciate our civilization, the inhabitants of the countries bordering on the Red Sea are far superior to those on the Atlantic. It does not seem well to begin with those who are the least prepared. We do not commonly expect success from operations conducted at an eccentric point. The Koran has spread because it has availed itself of the great lines of trade, which reach from the Red Sea to the interior of the continent; it has spread, not because

Prospective civilization of Africa.

of its doctrinal theology or theoretical politics, but because it is concerned in the amendment of the social condition of the people. That is precisely the principle which accomplished the civilization of Europe; and, with regard to the capacity of those nations to receive Christianity, we may, even to our shame, recall the circumstance that the Abyssinians are yet a Christian people, still retaining the ancient faith delivered to them in the apostolic ages, when our forefathers were pagan barbarians. Surrounded by the most depressing and antagonizing influences, they have held fast to their faith for nearly eighteen centuries. The hoary Abyssinian Church carries us back beyond the Council of Chalcedon and the disputes of the Eutychians; its literature is full of the questions which exercised the faithful in the primitive times of the brethren at Jerusalem—circumcision, things strangled, meats prohibited by the law of Moses; and yet, to the discredit of the European and American, it must be said that this Church, full of incidents of the most singular and touching interest, has scarcely had (with one exception) any sympathy extended to it by other Christian people.

Spread of Christianity in the two Americas.

From these considerations of the effects of Asiatic civilization upon Africa, we may profitably turn to a brief statement of that of Europe upon the red races of America. This result in the two continents, north and south, is, that in the latter, out of almost 1,700,000 aborigines, nearly 1,600,000 have embraced Christianity, less than 100,000 remaining in the savage state. No such favorable impression has been made upon the aborigines of the northern continent, who, as is well known, are steadily diminishing in numbers, and many tribes that were once numerous have disappeared. This has taken place notwithstanding the care which has been manifested by the government of the United States for all those who are within its territories. It does not appear that the conclusion which has been drawn by some eminent authors in view of these facts can be maintained, that "this consideration, if we can separate it from the events of the Spanish conquest, for which it is to be hoped that the soldiers, and not the ministers of religion, are responsible, must be allowed to reflect honor on the Roman Catholic Church, and cast a deep shade on the history of Protestantism."

That this conclusion is incorrect is shown at once by the very tables that are relied on for its support. Out of the 100,000 aborigines of South America who remain heathen, more than 66,000, that is to say, two thirds, belong to the Araucanian and Patagonian branches, who are the counterparts for that continent of the Indians of the United States and British American territories in this. Upon these it may be truly said that no impression whatever has been made. Of the Patagonian branch, estimated at more than 32,000, only 100 individuals are stated to have embraced Christianity, and of the Araucanian branch, consisting

of 34,000, not one. It is by bringing into these discussions the singular and widespread error that all the aboriginal American tribes are alike, and by not making due allowance for their habits of life, their physical and mental endowments, that this mistake has arisen; but whoever will consider the facts as they actually stand must come to the conclusion that there are just as well-marked differences among these people as there are in the climates and circumstances in which they live. Intellectually, there is even a greater difference between the Indian of the United States and the Indian of Peru than there is in their physical aspect. The one is an intractable savage, the other docile and easily led; the one has never yet been enslaved, the other prospers and increases in number, though he has sustained all the consequences of the atrocities of the Spanish Conquest. By chance, or perhaps, as we should more truly say, through Providence, the field of Catholic labor has been among the more docile races, that of Protestant among the more untamable, and the result is exactly such as, under those circumstances, the philosopher would be led to expect.

I can not here avoid recalling to the attention of the reader what I have said respecting the comparative progress of Christianity and Mohammedanism in Africa, for we find upon our own continent a repetition of the facts which were presented to us there. The chances, if such a term can, on this occasion, with propriety be used, of the diffusion of Christian civilization, are directly proportional to the existing intellectual development of the community among whom the attempt is made. Mohammedanism has diffused itself in Africa for precisely the same reason that Catholicism has succeeded in America—because its operation was commenced upon those tribes best prepared to receive it.

Illustration of the effect of climate on civilization.

We can not have a more striking instance of the effect of climate on civilization than that which is offered by the American Indians. As is well known, though throughout all those latitudes in which life is maintained with difficulty, by reason of their inclemency, all the tribes, both of the north and south continent, were in a barbarous state, yet in those more pleasant countries toward the equator, in which, by reason of the natural fertility of the soil and a higher mean temperature, the inhabitants had little occasion to work, and passed their lives in comparative plenty and ease, a special civilization had arisen. It is of no little interest to observe how the main features of Asiatic and European civilization were presented in this case, doubtless without any communication with those continents, for it shows how the human mind is ever prone to unfold itself in the same way, to give birth to the same ideas and to the same inventions.

Civilization of the tropical Indians.

The civilized Americans of Mexico and Peru were organized in communities not unlike those with which the white man is

elsewhere familiar, living in cities which were regulated by municipal laws familiar enough to us, maintaining among their social institutions, fixed ideas respecting property and family rights, having a national religion, an established priesthood, and the means of recording events, which, though imperfect, were not unlike those which obtained in the earlier periods of our own civilization. If they had not a knowledge of iron and the plow, they had already fallen upon the early Asiatic plan of subjugating and domesticating such animals as were suitable for their purposes. Civilization arose among these people in similar localities and under similar circumstances of life as it had arisen among our ancestors in the Old World, and, such is the sameness of constitution of the human mind, was advancing in exactly the same way.

Gradual extinction of the Indians of the temperate zone.

Although, for a time, among the degenerate descendants of the Spaniards, the South American Indian may maintain himself, but little doubt can be entertained that the same destiny awaits him which has befallen his North American brother. He can not withstand that enterprise and activity which are leading to the extension of the white invaders of his native soil. Even though the age of cruelty to these unfortunates has passed away, never more to return, and enlightened governments, animated by sentiments into which no mercenary consideration enters, interest themselves in their welfare, it is not to be supposed that nations depending on such an artificial support can long continue to exist. In this inevitable decline, the tropical races may far more worthily excite our commiseration than those of the higher latitudes; nor is their departure unavenged: they leave behind them two curses, tobacco and syphilis.

Manner of progress of all nations in civilization.

In conclusion of this partial examination of the progress of the human family under varied circumstances, we may remark a repetition of a like series of changes to those which have been traced in the psychical career of the individual, and this, whether we consider the progress in theology, policy, philosophy, or any other respect. It is a continued passage from the general to the special —from the homogeneous to the heterogeneous. The history of any of the ancient nations might be brought forward as an example. Emerging from the barbarous state, they shake off their Fetichism, that union of the supernatural with the natural, which gives to every wood, every tree, every river, its presiding genius; to families, their Penates; to the city, and even to the road, their Lares; to stars, and to stones, and to medicines, their spirits; to the night, its apparitions and fairies. It is in vain that we say these are the subjects of African credulity. They are found in the origin of all people. Our forefathers once cherished the illusions which still occupy the negro mind. The time came when intellectual development outgrew such base superstitions, and for a crowd of

imaginary inanities were substituted the chosen forms of Polytheism. It is true that, among Egyptians, Hindoos, or Greeks, there were deities enough, but the process of specialization may be nevertheless plainly discerned. The Fetich stage, the Polytheistic stage, are necessarily included in the onward progress to a pure metaphysical Monotheistic conception. In this it is to be remarked that the Asiatic races of men have led the way, both in the priority and strictness of their views. The great statesmen of China, of India, of Arabia, and of Judea, centuries ago, seized upon this as the pivot of their intellectual and even political systems. To the last country, Europe itself, as history proves, is indebted for this noble idea.

Their religious persuasions.

European Monotheism is not indigenous, but imported from the Hebrews, an Asiatic race. The intellectual condition of the nations among whom it was introduced was but little advanced, and hence among some it came to be degraded—mixed up with the remains of popular and anthropomorphic conceptions, which otherwise were gradually dying out. For a length of time the pagan creeds maintained a conflict with it, and with difficulty it disentangled itself from the base features which they endeavored to impress upon it, as with the Hebrews themselves of old, the people seemed to be reluctant to surrender altogether their Polytheistic ideas.

These remarks are to be understood as not applying to individuals, for in every age and nation great men have arisen, whose views on these and other subjects of like vital importance were far in advance of their times. In their best days, both in Greece and Rome, there were men who had attained to the standard here alluded to, but their teaching was without effect on the popular mass. There was a want of equivalency between the individual attainment and the race attainment. Though individuals may be progressive, races are essentially conservative; and hence there will constantly arise against individual attempts at an advance discountenance and resistance, an opposition which in too many instances becomes a tyranny. Masses of men are not like inorganic masses, which resist a change by their inertia alone. The biography of every great reformer shows that the popular mind resents any disturbance of its repose. Resistance has to be overcome in the moving of things, resentment is added in the moving of men.

To the philanthropist it is a most delightful spectacle that the various nations, in spite of the difference of their interests, their creeds, and their politics, can yet present certain great principles which they recognize in common, and this is becoming more and more marked with the onward advance of the world. In the course of events, the special is ever coming out of the general, and the great principles of a common morality are gradually disentangling and

Existence of a common morality with discordant creeds.

unfolding themselves from contradictory forms of faith. The Chinese, the Hindoo, or the Turk, though they may not coincide with the American or European as to what is to be looked upon as true, will yet agree as to what is just. The sentiment of honor, the ideas of personal integrity, are fast becoming universal.

Yet even in these later ages, there is in this respect nothing new. The tendency of the human mind, whether individual or collective, to the same direction is continually manifest—a premarked and predestined course in which it must go. Our most refined notions of rectitude contain nothing more than is to be found in the little epitome of the ancient lawgiver; for if we strike from the ten commandments whatever is explanatory or threatening, retaining the mandatory parts alone, there remains what commends itself to the understanding of intelligent men even of the most diverse nations—the acknowledgment of the unity of God, the veneration due to him, the expediency of a day of rest for the laborer, the duty of filial affection, the enormity of murder, the sin of adultery, the crime of stealing, the shame of lying, and a strict regard for the property of another: these are things which exact for themselves a spontaneous and universal assent.

CHAPTER VIII.

SOCIAL MECHANICS.

Comparative Sociology.—Connection of Structure and Habit.—Connection of History and Physiology.—Insect Society.—Descartes's Doctrine that Insects are Automata.—Necessity of a Mechanism of Registry for Instinct, Reason, and Civilization.

Nature of Man.—Influence of surrounding Circumstances on him.—Definiteness of his Career.

General Facts of European History.—*Introduction of Egyptian Civilization into Europe.—The Registry of Facts by Writing.—Egyptian Philosophy in the Greek Schools.—The Persian Empire: its Influence.—Analytical Quality of the European Mind.—Influence of the Greek Schools on modern Philosophy.*

Origin of European Commerce.—Discovery of the Straits of Gibraltar.—Macedonian Campaign.—Reconstruction of Monarchy in Egypt.

The Roman Empire: its centralizing and civilizing Power.—Fall of European Paganism.—Influence of the Christian Church.—The Sabbath Day.—The Reformation.

Influence of Mohammedanism on Europe.—The Arab physical Science.—The Crusades.—Discovery of America by the Spaniards.—Fall of the Spanish Power.

Later Mental Changes in Europe.—Disappearance of Credulity.—Physiological Change of Europeans.—Effect of Mohammedanism in changing the Centre of Intellect of Europe.—Analytical Tendency of the European Mind.—Advantages resulting therefrom.

Dependency of social career on structure.

Having described man as an individual, we have next to consider him in his social relations; for so closely are his actions connected with his organization, that it may be said that universal history is only a chapter of physiology. It is acknowledged,

even by those who have given but a superficial attention to the subject, that there is a connection between corporeal development and historical career; that those races who have led the way in the course of civilization, and those who still remain in the savage state, are characterized by striking anatomical peculiarities, particularly in the size and development of their cerebral hemispheres. Such general conclusions are strengthened by our observations on the animal series, the lower members of which offer together a sameness of structure and an identity in their course of life. In those the metamorphoses of which have been studied, it is always noticed that every change of structure is at once followed by a change of habit, yet, during the continuance of a given condition, their manner of life is without any variation. The actions of one insect are for the most part the actions of another of the same kind and in the same state, whether larva, pupa, or imago. But in the midst of all this automatism there are, however, the glimmerings of a free will. The animal world presents forcible illustrations on every hand on the connection of structure and habit.

Structure and habit in the case of insects.

Philosophical views of human sociology are only to be attained by treating that great problem in the same manner that we have learned to treat so many others in physiology. We must include in our discussion all other animal races, and not close our eyes to the fact that there is such a thing as comparative sociology. We observe the republican propensities of the ant, the monarchical life of bees, the solitary habit of other tribes. Is it not, at least in part, because of cerebral peculiarities that one kind of bird is polygamous, and another observes an annual or perpetual monogamy; that the buffalo delights in the society of his kind, but the lion will tolerate no neighbor; that the horse runs in herds, and adopts an organized system, submitting to a captain whose motions he follows? We can not suppose that these habits are the sole result of a present and immediately active external influence which calls them forth; an internal influence is also at work, an internal influence dependent on organization.

Comparative sociology.

A discussion of the problem of human sociology could, therefore, only be completed after a study of the same problem in the entire animal series — a task requiring varied and profound knowledge of natural history and comparative anatomy. Indeed, the present state of these sciences does not enable us to accomplish it. The remarks I am about to make are, therefore, of a very imperfect kind. The social problems presented to us by animals are a fitting introduction to the social problems of man.

For the clearer understanding of what follows, it may therefore be observed that we may receive the term instinct as indicating a faculty incapable of improvement, and possess-

Distinction between instinct and reason.

ed by each individual exhibiting it spontaneously, without experience or imitation. The suggestions of instinct are often instantaneous and always unvarying; those of reason involve deliberation, and into them the element of time enters. They also involve error. Animals which, for a thousand years, nay, indeed, through all time, have never invented, never improved, never varied, all of the same kind being equally skillful, are to be considered as actuated by instinct, not by reason. Those of which it may be said that they perceive, remember, think, compare, and then form a judgment, are to be considered as possessing reason, and this the more as they the more perfectly accomplish that end. In this respect, man is approached by the quadrumana, the elephant, the dog, but the immense interval which separates him from them is at once indicated by the fact that they appreciate only good and evil, so far as involved in pleasure and pain; but he contemplates equally the good, the beautiful, and the true.

Connection of history and physiology.

The historian may perhaps view with resentment an attempt on the part of physiologists to accomplish the annexation of the territory in which he labors. With difficulty will he be brought to admit the dogma that the history of men and of nations is only a chapter of physiology. He doubtless will smile at the absurdities of a doctrine which places under a common point of view the doings of caterpillars, ants, and wasps, with the high resolves of senates and emperors—which undertakes to consider how, out of the most obscure, the most august may proceed.

But it is none the less true that there exists a comparative sociology, as well as a comparative anatomy and a comparative physiology. Structure, function, and career are all inseparably connected.

When we were considering, in a former chapter, the nervous mechanism of insects, we saw how that, from the purely automatic, the voluntary is gradually produced by the development on the ventral cord of an apparatus for the registry of impressions, the cephalic ganglia. These registered impressions are the cause of the most surprising psychical results.

Barbarism and civilization.

The action of barbarian communities is as purely automatic as the action of an insect, which never had, or from which there have been removed, the registering ganglia. Irritate the decapitated wasp, it will sting. The uninjured wasp has a choice of action; it may possibly fly away. The action of civilized communities is of a far higher kind: they are guided in what they do by experience. In the progress of civilization there have arisen the means of permanently recording past events. Such records influence us in deciding how we shall act. They constitute knowledge.

If we may compare small things with great, is there not an analogy

between the manner in which the registering mechanism of an insect or other animal is evolved, and the manner in which the means of perpetuating and disseminating a knowledge of events have arisen in human society? The one, it is true, appertains to individual life; but is there any fact more clearly made manifest by physiology than that of the parallelism of race life and individual life, no matter how lowly that individual life may be?

Analogy between individual development and social career.

An insect presents us with surprising actions, because it possesses within itself the means of registering the events which occur in its little circle. Nations act wisely and well, according as they are guided by their store of experience.

If our pride can be so far overcome as to admit that in the history of the life, even of an insect, the progress of mankind is shadowed forth, that is to say, universal history is seen in a microscopic manner, it will not be too much to hope that we shall then entertain physical or mechanical ideas of the social career, that society advances in a definite way, has its laws of equilibrium and movement, its centre of intelligence, its centre of power, in short its statics and dynamics.

Though it is only one out of many instances that might be presented, let us briefly consider social life in the inferior tribe to which reference has been made; let us also look at some of the individual peculiarities of insects. Our sentiments of exclusiveness and pride may be corrected thereby.

Insect society.

Insects form societies for mutual assistance, defense, invasion, emigration, mere pleasure—societies which undoubtedly arise in the experience of passions, such as love and fear. Of these the duration is variable; some last through the larva state only, some are confined to the imago, some are maintained through life. The organization by which their object is accomplished is various, monarchical, republican. The caterpillars of the processionary moths are guided in their march by a leader; the termites obey at once a king and a queen. The lust of power is not alone felt among human monarchs; the queen bee never rests till she has assassinated her rival. All insects of the same kind are not born equal, nor do all pursue the same occupation; some follow a life of leisure, some devote themselves to the profession of arms, some are laborers. When the metropolis of the termites is attacked, the laborers, as non-combatants, retire, but the soldiers come out. The ants, with which we are more familiar, engage in military and fillibustering expeditions; they make reconnoissances, set sentinels, march in a definite order, the van alternately falling to the rear; their lines of communication are maintained, and, if necessary, swift couriers are dispatched for re-enforcements. If successful, they not only carry off the enemies' stores, but reduce the vanquished to actual servitude, compelling

them to work as slaves. They have notions of property, and, though some of them practice cannibalism, they will amuse themselves in more pleasant occupations, tumbling and playing together like kittens or puppies. With a sentiment of strict justice, the wasp who has returned from a successful foray divides his booty among the males, females, and the laborers who have been working in the vespiary; nor is the sentinel, who is doing duty at the door, forgotten. If, through the chances of war or by accident, any one has sustained a grave injury, in some tribes the most devoted sympathy is shown: the ant will carry his wounded friend out of the hot of the fight; in other tribes a more than Roman firmness is displayed: the sufferer is put out of pain by his companion. Expecting an attack, some insects will shut their doors at night, and barricade them within, or, if the danger is continual, will build masked gateways in succession, with interior walls that command them. They are no contemptible engineers. They can construct and maintain roads of great length, with paths branching from them, which, if necessary, they keep mown. They cross streams by throwing themselves into floating bridges, and the damage done to their premises by an invader they show the most singular skill and alacrity in repairing. How many are the contrivances to which insects resort to carry out their purposes! The caterpillar of the cabbage butterfly makes a ladder and goes up it; the geometrical caterpillar lets down a rope, and, for fear of hurting himself, drops a foot at a time. The gossamer spider sends forth a thread fine enough to act like a balloon, and, floating in the air, he descends or rises by winding it up or letting it out. There are other insects which make diving-bells, and go under the water. No bird makes a net, no beast a pitfall: men and insects do both. A gang of sailors will carry a spar by supporting it on alternate sides on their shoulders; a gang of ants will, in like manner, carry a straw or a long worm. There are spiders which show as much dexterity as an Indian in sneaking forward to get in reach of their prey.

Habits of insects.

In their domestic economy, how wonderful! Some build their houses of artificial stone, some of pasteboard which they make. Some cover their rooms with tapestry, some lay carpets of silk on the floor, some hang their doors on silk hinges, so that they shut by their own weight. They make arches, domes, colonnades, stair-cases. They practice concealment of food. Ray, an accurate observer and a very pious man, says of a sand-wasp that it carried a caterpillar fifteen feet, removed a pellet that closed the mouth of a hole, deposited its booty therein, came out, and rolled the pellet back on the hole, scratched dust thereon like a dog, went for rosin to agglutinate it, leveled the ground, and put two pine leaves to mark the place. However much we may smile at this anecdote, it may satisfy us of the high opinion entertained of the accom-

plishments of insects by those who have been close observers of their habits.

Dr. Laycock remarks, when speaking of the cephalic ganglia of insects (Med. Chir. Rev., July, 1853): "On what structures depend, if not on these cephalic ganglia, all those wonderful instincts which mimic in their operation the arts of man? There is hardly a mechanical pursuit in which insects do not excel. They are excellent weavers, house-builders, architects. They make diving-bells, bore galleries, raise vaults, construct bridges. They line their houses with tapestry, clean them, ventilate them, and close them with admirably-fitted swing-doors. They build and store warehouses, construct traps in the greatest variety, hunt skillfully, rob, and plunder. They poison, sabre, and stab their enemies. They have social laws, a common language, divisions of labor, and gradations of rank. They maintain armies, go to war, send out scouts, appoint sentinels, carry off prisoners, keep slaves, and tend domestic animals. In short, they are mentally a miniature copy of man."

Instincts of insects depend on their cephalic ganglia.

The surprising character of some of these facts might disappear were we acquainted with what may be termed the spring of the action. It has been said by Dr. Whateley that the building of a comb is like the provisioning of a city, in which, through the desire of the dealers to get wealth, is solved what is probably the most intricate of social problems. It is done by no design of theirs, and yet they advance to it as if impelled by gravitation or some other insuperable force. A printer may put types together to get money without ever troubling himself about the diffusion of knowledge. A bee may find gratification in what he is doing without any concern about the final use of the comb.

Of the cephalic ganglia spoken of in the preceding paragraphs, *Fig.* 295 is an illustration from Mr. Newport, in the case of the imago of the Sphinx ligustri: *a*, cephalic ganglia; *b*, *b*, eyes; *c*, anterior median ganglia; *d*, *d*, posterior lateral ganglia of the stomato-gastric system; *e*, *f*, large ganglionic masses in the thorax, giving nerves to the legs and wings. It is to be understood that upon these ganglia the voluntary action of insects depends. They are the places of reception of the impressions on the organs of special sense and the seat of memory. The automatic or involuntary apparatus is in part seen at *Fig.* 296, which is the thoracic portion of the nervous system of the pupa of the same insect: *a*, *b*, *c*, three ganglia of the ventral cord; *d*, *d*, their connecting trunks; *e*, *e*, respiratory ganglia. The entire

Fig. 295.

Cephalic ganglia.

Nervous system of insects.

Fig. 296.

Thoracic portion of ventral cord.

nervous mechanism for the larva state has been shown in *Fig.* 126; for the pupa, 127; for the imago, 128; from which it will be recognized that the nervous system of insects, as they pass through their metamorphoses, undergoes change. In the larva state, the nerves, as they branch forth from the ventral cord, indicate by their uniformity the equality of the segments of the body. In many cases the cord is separated throughout its whole length into its two constituent strands, and the cephalic ganglia are minute because of the imperfect condition of the organs of sense. In the pupa state there is a general approach of the ventral ganglia, an increase of the cephalic, and a thickening of the strands which connect that organ with the subœsophageal. In the imago state the cephalic ganglia have still farther increased to a size which corresponds to the great development of the organs of sense; the ventral ganglia appear to have coalesced in the thorax. The general result of these changes during metamorphosis is therefore to effect a concentration of the nervous centres in the head and in the thorax, the ganglia of special sensation coalescing in the former, and those of motion in the latter region. We may remark that these modifications strikingly illustrate the observation that change in habits of life is always preceded by change of the nervous system.

Changes in the nervous system during insect metamorphosis.

Besides being the repository of the impressions of the special senses, the cephalic ganglia discharge a function of a more general and most important kind, since doubtless they are the seat of memory. That insects of the more elevated kind have the power of recollection there can not be any doubt. If there were no other fact, their recognition of their homes would be sufficient to establish this. A thousand trivial incidents offer indirect, but instructive and interesting proofs of the same thing. When a spider who has been disturbed feigns death in order to avoid the cause of his alarm, he proves his capacity of recollection, as also when he has been brought out from his concealment by touching his web, and, discovering the nature of the imposition that has been practiced upon him, refuses to come forth upon a repetition of the trial. The quality which the cephalic ganglia thus possess of bearing upon themselves the enduring traces of impressions received through the sensory organs scarcely requires here to be more particularly examined. In the preceding book, in the chapter on inverse vision, various facts have been mentioned which illustrate the faculty possessed by the optic centres in man of retaining visual impressions for a considerable period of time; as, for instance, if, when we awake in the morning, our eyes are directed to the bright window and then closed, a representation thereof will still continue to be seen in its natural colors and relations, a representation which gradually fades away; and, in like manner, the cephalic ganglia register the impressions they receive from the optic,

Seat of memory in insects.

the auditory, olfactive, and other nerves that pass to them, and preserve the vestiges thereof; for, if this be not the case, it is wholly impossible to explain how insects should have the power of remembering, even though it be indistinctly or imperfectly, things that are past: those things or effects must have left upon them an enduring mark.

The cephalic ganglia are registers.

The ganglia of the ventral cord, with their related nerve trunks, constitute a series of automatic nerve arcs, their immediate object being locomotion. As has been said, the impression of the surface upon which the insect rests gives rise, under ordinary circumstances, to muscular contraction, and thereby motion, and the same thing occurs under circumstances of unusual experimental disturbance, as when irritation of any kind—for instance, the pungent vapor of ammonia—is applied to one side of a centipede, the body is flexed in such a way as to get rid, as far as possible, of the noxious fume. These movements are purely reflex, and in their production the cephalic ganglia are in no manner concerned.

Action of the ventral cord alone.

Guiding and controlling these purely reflex operations, the cephalic ganglia, by means of the fibres which they send in company with the trunks of the ventral cord, can exert their influence in the remotest part of the body. That influence we distinguish as being of a twofold nature: in part it is due to impressions which are being at that moment received through the various organs of sense—the eye, the ear, or whatever other such organ the insect under consideration may possess, and in part arising from the residues of old impressions which the ganglion has formerly received. It does not therefore seem possible, at least as regards the more perfect of these tribes, to accept the views of Descartes, who regarded all insects as mere automata. They are automata only so far as the action of their ventral cord and that portion of their cephalic ganglia which deals with contemporaneous impressions is concerned, but they are not automata, since they are under the influence of those ganglia as the registers of past impressions.

Controlling action of the cephalic ganglia.

Descartes's doctrine that insects are automata.

What has been said respecting insects applies to all higher tribes of life. Man himself is no exception. In the preceding book we have shown that, so far as his spinal nervous system is concerned, he is simply an automaton, and that it is the development of a brain thereupon which makes him capable of voluntary action. We have seen that in his individual progress part is evolved from part, an ever-increasing complexity and an ever-continuing improvement.

It is the same, also, with the group to which he belongs—the vertebrates. Just in proportion to the advance of their cerebral mechanism are their psychical powers. The amphi-

Cerebral mechanism in animals connected with psychical powers.

oxus, which has no cerebral hemispheres, represents the condition of man when the action of his brain is suspended in sleep; the fish, the reptile, the bird, follow in an ascending order—an order which man himself passes through in his individual progress of development.

And man in the aggregate—in society—in the race—does the same, his historical career being a transcript of his individual career. Generation after generation leads a purely automatic life, the life of barbarism; but, by degrees, there is evolved in such conditions the means of registry or record. The acts and thoughts of one age can then be transmitted to another, and can influence its acts and thoughts. Civilization can not exist without writing, or the means of record in some shape.

Writing is the means of record for society.

Writing once invented, the advance in society is again precisely as it is in the individual. In part it is regulated by the physical circumstances around, in part by the interior—the acquired principle.

In the superficial sketch which I intend now to give of the progress of European civilization, there are certain facts which, from their prominence, can not fail to arrest our attention. They are,

General facts of European history.

1. Europe remained in the barbarous state until it obtained the means of perpetuating ideas, that is to say, until it learned the art of writing.

2. The progress of civilization in Europe was attended by an absolute physiological change in its inhabitants. They were brought nearer to the condition of the inhabitants of a more temperate climate. On this point, however, we have dwelt to a sufficient extent in the preceding chapter.

3. The European mind is analytic, that of Asia is synthetic. In Europe, the action in philosophy, in religion, in politics, tends to the incessant decomposition of a thing into its parts, and their separate discussion. The results of this tendency are seen in many of the practical social difficulties of modern times.

Before entering on this, the conclusion of his work, the author may recall by a few passing remarks the general views which have been incidentally scattered through preceding pages respecting the nature of man, the influence of surrounding circumstances over him, his social position, the definiteness of his career, a definiteness which authorizes us to treat his history, not as though it were composed of chance events, but as a fitting subject for the contemplation of physiology.

Man is every where constructed upon the same essential type, and hence, in one sense, he acts in an invariable manner, but that type passes forward in development to many different aspects, and hence, in another sense, he exhibits differences in his determinations and movements.

With the form and size of the brain, the intellectual capacity of man

varies. In a state of nature, his mental powers are in close relation with the climate in which he lives, attaining their greatest perfection in the warmer portion of the temperate zone; but under the artificial condition of civilization, in which the vicissitudes of the seasons are compensated for by food, fire, shelter, and clothing, properly adjusted, he gains his maximum development in a somewhat higher latitude.

After what has been said in the last chapter respecting the influence of physical circumstances on the structure of man, producing modified development in our typical form, and thereby giving rise to many distinct families, it will be anticipated that those circumstances must consequently modify our mental operations, our manner of thinking and acting, that is to say, must leave their marks on our history as nations. For a long time this has been recognized in a general manner: the mountaineer thinks differently and acts differently to the native of the lowlands; he whose life is spent on the borders of the sea to him who lives in the great plains in the interior of continents. But it is not to these influences as operating by association on the individual that I now refer; it is rather to the profound effect they have had in producing a special cerebral, and, therefore, mental organization in the course of many generations on races and nations.

Let us always remember that there is a common principle which underlies the varied movements and determinations of men every where—a principle from which no one can disentangle himself. At the bottom of even the most diverse actions it may be discerned, just as we can detect the fundamental type of our organization under the most varied forms.

Nature of man.

As from the physical point of view there is a standard man who, in weight, height, strength, and other such like particulars, represents the entire human family, so, in an intellectual point of view, there is a standard man who, in mental progress, manner of thinking and of acting, represents the whole race. There are also subordinate standards, the representatives of particular groups or nations. It is to these standards that we are continually appealing in arriving at a judgment of the acts of individuals. The special history of these phases constitutes, in a philosophical sense, national history. The record of the development of the fundamental type constitutes universal history.

Influence of surrounding circumstances on him.

I have already remarked that universal history is only a chapter in physiology. Since, by reason of the similarity of construction of the cerebral apparatus, the actions of men will present a uniformity when under the influence of similar motives or impulses, there is not only a resemblance between such actions among different persons, but also it may be discerned when nation is compared with nation, and race with race; for the movements of communi-

ties depend on the same motives as the movements of individuals, being indeed the sum of individual determinations. But when multitudes and masses are thus brought under our consideration, the element of free-will seems for the most part to disappear, and events assume an air of predestination. To this principle it is that history owes its chief value, and truly becomes, as is often said, philosophy teaching by example. The intelligent man who lived twenty centuries ago would doubtless have come to the same decision which is reached by the intelligent man of our times; the same propositions being submitted to both, both guiding themselves by similar principles to a like result. The logic of truth is eternal, for it is the expression of the manner of action of our cerebral apparatus, the type of which never changes; and since there is thus no essential change in the typical construction of man, and therefore none in the manner of operation of his mental processes, since physical nature is unvarying, and the events of life spring one out of another in a regular order or sequence, there must arise those same analogies in the history of race compared with race, and nation compared with nation, that are so obvious when individual is compared with individual. Of every great future event there is therefore a past history, for every such event has had its precedent in other histories, and therefore its prognostic. Things will follow in a definite order so long as the influences of external nature are the same, and so long as the construction of the human brain is the same.

Definiteness of his career.

The political foresight of the most eminent statesmen depends on a gift of appreciating national mental types, like that possessed by great sculptors or painters of appreciating a standard of beauty. It is this which enables them to foresee the probable consequences of events, and to realize the expected action of individuals, and even of masses of men. In such actions there is far more uniformity than is commonly supposed. The same general conditions which yield to the post-office a definite percentage of misdirected letters every year—which, with marvelous fidelity, give to the hospitals, the jails, the bills of mortality, their expected numbers, operate from age to age, and in one nation as in another, and hence arises that appearance of fate in the action of masses to which we have alluded; hence also it is that the same cycle of events re-occurs again and again, diversified, perhaps, but never essentially changed by the influence of individual free-will. As the comparative anatomist exhibits, in the different members of the living series, their common points of resemblance—that this organ in one animal is the homologue of that in another, and this function the analogue of that, so the philosophical statesman, acknowledging the essential principle of comparative history, reasons from nation to nation and from age to age.

CHIEF EVENTS IN THE CIVILIZATION OF EUROPE.

Europe emerging from barbarism.

The Odyssey presents us a vivid picture of the state of Europe a thousand years before the birth of Christ. A twilight was breaking on the most eastern verge in the countries adjoining the Hellespont, but the West and the North were immersed in a night of barbarism. The unfolding mind is ever prone to fill darkness with imaginary creations, and it was with the white race at that period as it is with a child. Every shore of the Mediterranean and Black Seas was full of prodigies. To the Greek no fiction was too marvelous for belief if it was separated from his view by a hundred years or a hundred miles, the exaggeration of tradition confirming it in the one case, and the difficulties of travel in the other. His horizon was crowded with enchantresses like Circe, sorcerers like Tiresias, monsters like the Cyclops. Gods and goddesses were perpetually flying through the air; every hill had its supernatural legend, every forest its phantom. Even the mouth of hell was on the farther side of the Euxine.

A religion of superstition is very liable to be connected with a life of evil works. The maritime enterprise of those days seems to have received no little incitement from the temptations of piracy — a profession to which, even at a later period, the Greek appears instinctively to turn; nor were these felonious expeditions restricted to the taking of goods; they drew an additional profit from the stealing of men. The evidences of even a still darker crime may also be discerned, since there were people accused by common fame of eating the captives who fell into their hands. The white man, therefore, emerges from his state of barbarism a pirate, a slaver, a cannibal, cruel in his moment of power, and debased by an incredible superstition in his moment of fear.

Civilization originated in Egypt.

Unable to originate his civilization for himself, he drew the elements of it from another country. By the concurring testimony of all authors, as well as the internal evidences of ancient history, that great blessing is the gift of Egypt. For thirty-four centuries before our era that country was governed by dynasties of kings, succeeding each other without interruption. Its soil, proverbially fertile, sustained a population, estimated, in the most prosperous times, at about seven millions; and repeated military expeditions into Asia and Ethiopia had, in the course of ages, concentrated in it immense wealth, the spoils of conquered nations, and crowded with captives and slaves the Valley of the Nile.

Ancient condition of Egypt.

For this long continuance of the Egyptian polity satisfactory reasons may be assigned. In early ages, when maritime expeditions were necessarily feeble, the country was open to invasion only across a narrow neck of land on the east, and was protected from any attack on the west by impassable and interminable deserts. Under

the military system of remote antiquity Egypt was almost inaccessible; but through the changes of later times, and ever since naval expeditions have been carried to any extent, her position has been that of extreme weakness. The uniform experience of twenty-five centuries, from the Persian wars to those of the French Revolution, has shown that the possession of the mouths of the river is equivalent to the conquest of the country.

In the security of this inaccessible retreat, and under political institutions of a favorable character, the civilization which was to be conferred on the white man originated. For a succession of centuries, industrial art, and its parent, natural knowledge, appear to have undergone a steady development; perhaps, as in other countries at a later time, advancing in the more prosperous political seasons, and becoming stationary in the decay of the empire. The statements furnished to us by Greek authors are of very little value, for as long a period of time intervened between the first Egyptian kings and them as from them until now. It is rather from the monuments of the Egyptians that we must judge. Each year since their country has been open to investigation, and their hieroglyphic system understood, the impressions we have received of their intellectual advancement have been more and more favorable. The vocal statue of Memnon at Thebes, it is said, emitted a musical sound when touched by the rays of the sun. In the light of modern criticism, every obelisk and monument in those desolated palaces is finding a voice.

Manners of the Egyptians.

The public works attest to this day the greatness and permanence of the Egyptian monarchy, and the peculiarities of the Egyptian mind. From the statues and ruins of the temples of the Greeks we see what a vivid perception that people had of the beautiful. The statues, and tombs, and temples of the Egyptians offer a striking contrast; the useful every where predominates. The vases of the one were adorned with emblematical and graceful forms; the tombs of the other were covered with sculptures and paintings, commemorating the ordinary pursuits of life, and various processes in the arts and manufactures.

These sculptures and paintings show to what an extent the physical sciences and arts depending on them had been cultivated. They set before us the domestic life and daily business and trades of the people: cookery, confectionery, glass-blowing, weaving, pottery-making, manufacture of cotton, painting on wood and stone, staining of glass, and a hundred other occupations. Among the pictured representations, a chemist sees with pleasure the apparatus of his art, siphons, bellows, blowpipes, etc.

Shut up by its political system from the Mediterranean nations in the same manner that the Chinese and Japanese empires have been in later times from other states, Egypt was to the Greek a land of mystery and

marvels. The exaggerated legends which had been brought from it at distant intervals by those who had escaped by stealth, or in troublous times had, like Cecrops and Danaus, led forth colonies of emigrants, lost none of their wonders in the traditions of successive generations, but were rather verified by the roving pirates who had seen the pyramids, obelisks, and sphinxes, and the great temples on the banks of the Nile.

The first step in civilization is the invention of some system of permanent record—some method of writing. Without this, it may be truly said that law can not exist. Law can not maintain itself in the uncertainties of tradition—law, without which we can not conceive of society. The legendary history of Europe is doubtless correct in referring to some of these Egyptian fugitives or emigrants the contemporaneous introduction of writing, and a system of jurisprudence. Even if the former was derived from Phœnicia, according to the story of Cadmus, the Phœnicians had originally borrowed it from Egypt. It is an interesting illustration of the tendency of the European mind to analysis, that of the forms of writing known in those times, the ideographic or picture-writing, the syllabic or the representation of syllable sounds by signs, and the alphabetic, the latter alone maintained its foothold in Europe. This form, as described at page 356, essentially consists in decomposing articulate expressions into their constituent vowel and consonant sounds, and assigning for each of those sounds a letter.

Introduction of writing from Egypt.

About seven hundred years before Christ, events took place which led to the extension of Egyptian civilization to Europe. The ancient power of the kings had declined, through disputes and compromises occurring between them and the priesthood. Between the priests and the military caste there was an open quarrel, many of the former having been deprived of their lands. These rivalries broke out in revolts and insurrections, and for two years the country was in a state of anarchy, from which a partial respite was obtained by an entire change in its institutions. Twelve of the most influential persons divided it among them, each having a province which he ruled as an independent king. The old monarchy had degenerated into an oligarchy, and it was this revolution which introduced African science into Europe.

Introduction of Egyptian civilization.

Psammetichus, one of the twelve, had for his province the country which borders on the Mediterranean Sea. Availing himself of his position, he established an intercourse with the neighboring nations, particularly the Greeks and Phœnicians, and amassed from it so much wealth that his colleagues, jealous of his increasing power, resolved to dispossess him. Until this time, all foreigners had been held in the utmost contempt, and rigidly excluded. Psammetichus called in the aid of Ionian pirates, and other Mediterranean adventurers, and, having collected a sufficient body

of such mercenaries, defeated his colleagues at the battle of Momemphis, and became sole ruler of the whole country.

Opening of the ports of Egypt.

By the aid of a foreign force the revolution had been ended, but the position of Psammetichus was essentially different from that of all preceding princes. A foreign force had given him the throne, and a foreign force alone could maintain him on it. Under such circumstances, he took his most politic course, and, breaking through the traditions of twenty-five centuries, opened the ports of Egypt.

This event necessarily led to a closer intercourse among the Mediterranean nations, and insured communication between Europe and Africa. The foreign element quickly made its influence manifest. In the very next reign the Cape of Good Hope was doubled, and Africa circumnavigated, and in the course of a very few years we find Pythagoras, Solon, and Thales visiting Egypt, and bringing from thence to Europe the elements of law and natural science.

The Persian empire: its influence.

The Persian empire in the mean time had attained an attitude of supremacy in Western Asia. Following the inspirations of its Babylonian predecessors, it was engaged in continual wars with its African neighbor. From the battle of Pelusium, and the conquest of Egypt by Cambyses, the political interests of that country and Greece became essentially the same. The Persian conquerors, operating alternately on the north and south shores of the Mediterranean, betrayed a determination to extend their rule around that sea, and make it a Persian lake. On the one hand they were resisted by the Greeks, on the other by the Egyptians, between whom active communications were kept up. For several centuries these operations were conducted with various success. The kings of Persia, several of whom seem to have been men of great capacity, comprehended the political advantages which would arise from the possession of the sea, and would have doubtless carried out their plans as respects the south shore, if the Phœnicians had not opposed obstacles for the sake of their colony at Carthage. And though the Greek historians, with a pardonable motive, speak of the various movements on the north as failures, there are many circumstances which lead us to receive their accounts with allowances. If Memphis was sacked, Athens also was burned; and even at the opening of the Macedonian expedition, Greek history is full of Persian incidents and intrigues.

Introduction of Egyptian philosophy.

In speaking of the Egyptian cultivators of philosophy as priests, the signification which is now attached to that word gives us an erroneous idea of what they really were. The colleges at Memphis, Thebes, Heliopolis, and Sais, were, in reality, each the head-quarters of a fraternity of artists and professional men, and bore *no* sort of resemblance to our modern ecclesiastical institutions. Among

them were architects, lawyers, physicians, painters, chemists, astronomers. These men were, moreover, the great landowners; not only were the temples richly endowed as corporations, but the individual members were persons of wealth. They enjoyed monopolies of all kinds; for instance, among other things they had extensive factories for cottons, and laboratories for the preparation of chemical products.

From these institutions the Greek philosophers brought natural science. Pythagoras had resided at Thebes, Thales and Democritus at Memphis, Plato at Heliopolis, Solon at Sais. They did at first little more than expound the doctrines they had learned. Their mode of instruction seems to have been, in many instances, founded on the Egyptian model. The Pythagorean establishment at Crotona may be regarded as a partial imitation of the African colleges.

The Greek schools.

It is not my intention to enter on an examination, or even enumeration, of ancient philosophical opinions, nor to show that many of the doctrines which have been brought forward within the last three centuries existed in embryo in those times. It may, however, be observed that, in the midst of much error, there were those who held just views of the various problems of theology, law, politics, philosophy, and particularly of the fundamental doctrines of natural science, the constitution of the solar system, the geological history of the earth, the nature of chemical forces, the physiological relations of animals and plants.

It is supposed by many, whose attention has been casually drawn to the philosophical opinions of antiquity, that the doctrines which we still retain as true came to the knowledge of the old philosophers not so much by processes of legitimate investigation as by mere guessing or crude speculation, for which there was an equal chance whether they were right or wrong; but a closer examination will show that many of them must have depended on results previously determined or observed by the Africans or Asiatics, and thus they seem to indicate that the human mind has undergone in twenty centuries but little change in its manner of action, and that, commencing with the same data, it always comes to the same conclusions. Nor is this at all dependent on any inherent logic of truth. Very many of the errors of antiquity have reappeared in our times. If the Greek schools were infected with materialism, pantheism, and atheism, the later progress of philosophy has shown the same characters. To a certain extent, such doctrines will receive an impression from the prevailing creeds, but the arguments which have been appealed to in their favor have always been the same. The distinction between these heresies in ancient and modern times lies chiefly in the grosser characters which they formerly assumed, arising partly from the reflected influence of the existing mythology, and partly from the imperfections of exact knowledge. Even the errors of early antiquity are venerable.

We must judge our predecessors by the same rules that we hope posterity will judge us, making a generous allowance for the imperfections of reason, the infirmities of character, and especially for the prejudices of the times. To have devoutly believed in the existence of a human soul, to have looked forward to its continuing after the death of the body, to have expected a future state of rewards and punishments, and to have drawn therefrom, as a philosophical conclusion, the necessity of leading a virtuous life—these, though they may be enveloped in a cloud of errors, are noble results of the intellect of man.

Analytical quality of the European mind.

The analytical quality of the European mind already manifested itself in this decomposition of knowledge derived from foreign countries, in this establishment of a host of schools, this examination and discussion of the fundamental elements of the imported philosophy. As there are differences in the physiognomy of races, so there are differences in their intellectual endowments, which, arising in peculiarities of cerebral construction, communicate peculiarities to the processes of thinking. The physical science of Egypt, transported to Greece, rapidly degenerated into speculative philosophy, and in so doing produced an instability of opinion which entailed as its consequence a laxity of morals. Such a social condition led naturally to the results which history indicates. It is not surprising that the most eminent men were open to bribery, and that the glory of those ages was so often the brilliancy of corruption. These are the necessary results attending such political conditions. Too often it fell out that the great men of Greece accused, and too often convicted each other of being influenced by Persian intrigues and Persian gold. In the general demoralization, they seem to have taken for their guide a perverted interpretation of the admirable precept of Solon, "In every thing thou doest, consider the end."

Greek irreligion.

Added to this, the public faith in things once implicitly believed was shaken. Xerxes in a very unceremonious way violated the temples and carried off their treasures, showing the same contempt for the gods of Europe that Cambyses had shown for those of Africa. If there lingered in the minds of the philosophers any latent belief in the national faith, a relic of the impressions of childhood or of popular opinion, such a practical demonstration could scarcely be lost. During the fifty years of that war, the philosophical opinions of the Persians had full opportunity to find their way among a class of men quite open to receive them, and from this time we perceive a striking similarity between many of the doctrines of the schools and the well-known dogmas of the Orientals. The Greeks, like the Hindoos, in the possession of the mere rudiments of science, passed at once to the discussion of the most *important* and elevated problems with which the human mind can be en-

gaged, and, as an inevitable consequence, were led away from true philosophy into sophistry and irreligion.

It has been remarked a few pages back, that in the progress of nations events follow in repeating cycles, and that for any one we may generally find its precursor, and therefore its prognostic. Greece dealt with the philosophy she had received from the southern people, African or Asiatic, exactly in the same manner that Europe dealt with Italian theology the moment that liberty of action was permitted by the Reformation. In each case the issue was not the prompt and final substitution of a system correcting apparent and acknowledged defects, a system in unison with the existing tone of thought. There was no such stoppage of action; but from the bosom of each principle and sect many other principles and sects arose, until there seemed to be no end to the subdivision.

Influence of the Greek schools on modern philosophy.

If thus we consider the political position of Greece, the condition of Asia Minor, occupied by Persian troops, the destruction that had overtaken Egypt, the excitements and calamities of a war of half a century, we can readily understand that this was not a season when the tedious and slow processes of true philosophy were likely to flourish, and that it was far more conducive to imposture than to science. The seeds of knowledge which had been brought from Egypt shot up into a rank growth, and Europe did not free herself of these weeds for sixteen centuries. The character of a long train of events is often determined at its inception; for this reason, I have dwelt in detail on those times, and it is well worthy of remark that the positive science of the European was not fairly established until after three distinct impulses from Egypt: once, as we have seen, under her Pharaohs; again, under her Ptolemies; and still again, under her Caliphs and Sultans.

Origin of European commerce.

While these events were taking place in the southeast of Europe, domestic and foreign commerce were preparing the way for a gradual diffusion of civilization. A trade with the countries bordering on the Baltic Sea for the amber which is found on those shores had gradually arisen, and, in like manner, another with Spain, France, and England for tin. The tin of Cornwall was carried through France and shipped by the Phœnicians at Marseilles, a certain quantity of the same metal being also obtained from the Spanish mines. Early in their history the Phœnicians had established colonies on several points of the Black Sea, and from these depôts they brought the various products of those countries, among which may be mentioned gold, which had apparently been originally derived from the washing of the Uralian deposits. This Black Sea commerce seems, however, to have been eventually abandoned for the more profitable Spanish trade, and on the withdrawal of the Phœnicians from the Euxine, the Greeks occupied their

Discovery of the Straits of Gibraltar.

place. Meantime the enterprise of the Tyrian sailors had carried them through the Straits of Gibraltar, and enabled them to have direct access with the tin and amber countries without the intervention of any overland traffic. It was doubtless the discovery of this outlet to the Atlantic which led to the destruction of the Gaulish trade in tin and the German trade in amber. So greatly was this latter substance prized, that the overland commerce in it had many ramifications: thus amber was carried into Italy by the Etruscans, who had a sacred road under the protection of the adjacent tribes to the Baltic Sea.

With their commerce the Phœnicians disseminated a knowledge of many inventions peculiar to themselves, among which may be mentioned the use of stamped metallic coinage. Their great African colony, Carthage, exerted in these movements eventually a more powerful influence than even the parent country.

Emulating the enterprise of the Phœnicians, the Greek mariners undertook expeditions both to the east and to the west, succeeding, as we have seen, in establishing themselves on the shores of the Euxine, and eventually passing, under Colœus of Samos, through the Straits of Gibraltar into the Atlantic Ocean; but even up to the time of the Macedonian expedition, their geographical ideas were very crude and full of errors. Of the expedition of Alexander, Humboldt remarks that it partook as much of the character of a scientific as of a military undertaking, and its consequences, both immediate and remote, upon Europe can scarcely be exaggerated. That great commander surrounded himself with whatever talent was to be found in Greece, and made his military successes for a time subservient to the science of his native country. It was through this that Aristotle obtained that commanding influence which not only gave him an authority over the active mind of his own times, but which was felt even until the introduction of the Baconian system of philosophy. The campaigns of Alexander doubled the geography of the Greeks in longitude, opened to their investigation new countries even to the tropics, brought them acquainted with races of men who had been the depositaries of science, as it then existed, for thousands of years, and, in short, added Asiatic to Grecian knowledge. It is a significant fact that, after the taking of Babylon, Alexander sent to Aristotle a series of astronomical observations reaching back through 1903 years.

The Macedonian campaign.

The Macedonian expedition not only made a profound impression on the European mind by its immediate results—its influence is equally palpable in its remoter consequences. It would be impossible, in such a sketch as this, to do justice to that great event in all its details; for nations can not be thus brought in contact

Restoration of monarchy in Egypt.

without prodigious mental results, the extinction of old, and the appearance of new ideas. But of the influences which thus arose, there is, however, one which deserves to fasten our attention, and the more so since we have had already, and shall have again, the occasion for alluding to it. It was the establishment of a regal government in Egypt. Under the Ptolemies, who may be truly characterized as the most illustrious kings of antiquity, that ancient country recovered her pristine glory. Among the works accomplished by these great men may be mentioned, as examples of their high-toned policy, the sending out an exploring expedition to equinoctial Africa; the establishment of menageries and zoological gardens at Bruchium; their attempts at determining the cause of the overflow of the Nile; the library at Alexandria; the museum at Rhakotis; the measurement of a degree on the earth's surface between Alexandria and Syene; the ascertaining of the prodigious distance of the region of the fixed stars; the recognition of the motion of rotation of the earth upon her axis, and of her translation around the sun; the precession of the equinoxes; the attempt at constructing a map of the world by the aid of degrees, based on lunar observations and on shadows; the improvement of the methods of astronomical observation by the invention of water-clocks, and instruments for the more accurate measurement of angles. Along with these, Baron Humboldt, in his Cosmos, has enumerated many other philosophical works of the Ptolemies, which exerted a profound influence both upon the knowledge and intellect of Europe. Greece now repaid what she had formerly borrowed; her schools of philosophy were translated to Alexandria, and the great names of Euclid, Apollonius, and Archimedes testify to the return of those ages to exact science.

The Ptolemies.

The decline of Greece and her final absorption into the Roman empire was the necessary consequence of her mode of life. In policy as in philosophy, her essential tendency was to subdivision, and therefore to weakness. In her external relations she had ever been far more closely connected with Asia than with Europe. For a long time she was little more than an outlying territory of Persia, respecting and fearing the highly-civilized nations in her front, but scarcely concerning herself with the barbarians at her back. Very different was it with Rome, her great supplanter and successor, who, thoroughly European in her whole history, exercised an active intervention in the affairs of adjacent nations—an influence perpetually felt through Spain, Germany, Gaul, and Britain.

Decline of Greece, and rise of the Roman empire.

It is difficult to estimate fully the influence of the Roman empire on the intellect of Europe. Its power lay not in the origination of what was new, but in the development and dissemination of what was derived from other sources. The contributions of the Roman emperors to the stock

of positive knowledge bear no kind of comparison to that of the Ptolemies just mentioned; indeed, their works have reference chiefly to military purposes and material aggrandizement. In this manner we must look upon the surveys and itineraries which they caused to be made of various parts of the empire. Nevertheless, through their influence the idea of civilization was gradually made to find its way through Central and Northern Europe.

Centralizing and civilizing power of Rome.

The function of Rome in our history is very distinct. From small beginnings she steadily pursued the same progress. The conquest and absorption of town after town, which was the history of her earlier times, was carried out in the annexation of nations in her day of strength. From the moment that she gained the control of the Mediterranean Sea, which was the grand epoch of her life, she inexorably forced all the conterminous nations to acknowledge Italian centralization. It is no metaphorical expression that she became their centre of gravity. No circumstance could occur to her which did not instantly influence them all. As far more than an equivalent for subjugation and loss of independence, she made them into a common race, harmonizing their actions, and giving them common ideas. The Roman empire was the organizing agent of the white man.

The acts of man, though they may have the aspect of free-will as regards himself, are automatic as regards the race. He is employed in achieving a result of which he is utterly ignorant; he is concerned in a work of the effects of which he is unconscious. He is like a bee, which doubtless experiences a certain pleasure in flying from flower to flower, the gratification of an obscure desire in constructing cell after cell, its individual delight ministering to a public good of the nature of which it is wholly unconscious.

In such a manner we may look upon the career of the Roman with satisfaction. He was pursuing a life of evil deeds, and accumulating in his great and dissipated capital the spoils of wasted provinces, gratifying his wanton luxuries by a systematic resort to war, that most awful of the curses that afflict our race. It was the temporary lust of individual interest that he was pursuing. Providence was bringing out of it a universal good.

The fall of European paganism.

If Rome was cruel in her national acts, she was majestic in her policy. She decimated nations that she might bind them into one family. With remorseless vigor she extinguished every trace of independent action, and with a contradictory but noble liberality, domesticated the worship of every conquered people round the Capitol. There was no god whose image she could not show, no faith of which she was not the patroness. It may serve as an example of the manner in which her policy led to definite results of which she

was unaware, or, if aware, of the manner in which the strong hand of Providence inverted her designs, that by this, her system of universal toleration of every ancient faith, she absolutely destroyed them all. Brought thus to bear upon one another at a common central point, their contradictions, inconsistencies, fallacy, and emptiness became apparent. The men of capacity first made the detection, their opinions spreading by degrees through society. Well might St. Chrysostom say that the error of idolatry vanished of itself, and that paganism seemed in his day "like a conquered city, whose walls were overthrown, her halls, theatres, and public buildings consumed by fire, her defenders slain, and here and there a few old men and children lingering among the ruins. Even these were soon found no more."

It is sometimes said that the Roman empire was essentially composed of cities; that at its fall its fragments were cities; and that it left nothing to posterity but its municipal system. Such a statement is not true. Its legacy was of a far higher order. It left the religion it had adopted, the civil law, and the foreshadowing of the great deeds that might be accomplished by the white man organized and united. To this, in a more perfect way, the affairs of our times are still conspicuously tending. We begin to hear of the opinion of Europe, the public law of Europe, expressions which are gaining each day more and more significance.

Influence of the empire in its decline.

In that phantasmagorial exhibition which we call history, events give birth to events as in dissolving views, the phantoms of the actors stalking one after another. It is not always possible for us, with the slender information we possess, to determine the time of origin of each incident, or its true and actual bearings. The secret history of antiquity is almost unknown. Nearly every circumstance in the decline of the Roman empire was fraught with important consequences for modern times. Among the more obvious facts which attract our attention are the dislocation of the centre of the empire by the translation of the seat of government to Constantinople, the consequent acquisition of power by the bishops of Rome in the West, the incessant emigrations and invasions of barbarians from the North, the conquests of the Saracens, from whom it seemed at one time that Europe would hardly escape, and that the threat of Muza would come to pass, that the name of Mohammed should be proclaimed in the Vatican; the consolidation of ecclesiastical policy, and the repeated attempts of the Church to suppress barbarism—attempts so signally successful that by the end of the eighth century many of those nations had written systems of law; the separation of the Greek and Latin Churches, the different phases which the latter assumed as she was affected by existing circumstances, how she extricated herself from an almost barbarous state after the empire had failed her, how she asserted the in-

The Papal government.

dependence of the spiritual order, how she kept her grasp upon mankind by the establishment of monastic institutions; how, after the death of Charlemagne, who had done so much for her, she adopted the feudal system, which was the legitimate offspring of barbarism; how, as knowledge began to spread, she tried to render it tributary to her by councils, convocations, federations; how, finding it likely to become uncontrollable, she took the alarm, and in an evil hour attempted its repression; how for a little while she became the autocrat of Europe, and in the plenitude of her power so greatly forgot her duty that, in the time of Leo X., it was doubted in Rome whether the soul be immaterial and immortal, Erasmus testifying with horror that he heard it proved that there is no difference between the soul of a man and that of a beast—of a truth it was said that the Eternal City teemed at once with all crime and all the glories of art—how, against the moral and intellectual revolt which she encountered—the Reformation—the Church made a stand by the aid of the Society of the Jesuits and the establishment of the Inquisition, and, with a quick sense of her true position, attempted to guide children through education by the former, and to check men by the terrors of the latter; how, as if by instinct, she detected the antagonism of exact science, and on the one hand published her Index of prohibited books, and on the other allied herself with art, cultivating it so eminently as to compel even her enemies to confess that she had produced true miracles at last—in architecture, sculpture, painting, music. Pius IV. was justified in comparing some of her grand masses to the strains of Paradise.

Its attempt at suppressing philosophy.

The mistake committed by the Italian government in thus attempting the compression of human thought was in its imperfect appreciation of the qualities of the European mind and the existing philosophical tendency. Up to a certain point opinion may be coerced by force. It is altogether a vulgar error that persecution never attains its ends. In nine cases out of ten it does attain them, provided it is applied with sufficient severity and for a sufficient time, as is proved by the history of almost any nation; but in the tenth it fails.

Failure of that attempt.

Judging from the experience of twenty centuries, for that was nearly the period during which the European had been philosophizing, the popes were justified in coming to the conclusion that they did. Those centuries had produced no philosophy of a sure and permanent kind. The only fruit which they had borne was the metaphysical uncertainties of the schools. There seemed no prospect that the human mind would ever do more than flounder in doubt; that sect after sect, and doctrine after doctrine, would emerge into prominence and disappear. In such a state of things, it was not to be supposed that any peril could arise from attempting to control opinion by authority, and to extinguish the spirit of inquiry by asserting the paramount efficacy of faith.

In thus failing to recognize the fact that things were coming to that condition in which the elements of certainty and absolute philosophical truth would be shortly attained, the popes committed the Church to an irreparable error. They periled her authenticity in an unequal conflict. It might do for a little time to deny and denounce the globular figure of the earth, but the demonstration of the truth came irresistibly at last; and so with the doctrines of the antipodes, the daily rotation on an axis, and the annual translation round the sun. It enhanced the folly of these proceedings that they were, in reality, insincere. Of the great ecclesiastics there probably were none who did not privately admit the truth of what was thus condemned. When the bark Vittoria, of Magellan's squadron, made the first voyage of circumnavigation round the globe, it was a high Church dignitary, Cardinal Contarini, who gave the true explanation of the circumstance, then first remarked, of the loss of one whole day in her reckoning. Such insincerity, and the issue of these and other like questions, could end in no other way—they sapped the prestige of the Church. How different would it have been if she had taken the lead, and directed the human mind in the channels through which it was destined to pass, instead of opposing herself as an obstacle! She might have guided, but she could not resist.

The Reformation.

It is to be remarked that the men who, from the twelfth to the sixteenth century, distinguished themselves in precipitating the result, were mostly ecclesiastics. Roger Bacon may be taken as the type of them all. Their labors had no little connection with the Reformation which was headed by Luther. Though we are accustomed to regard this with the most profound interest, a more philosophical view of the state of things may perhaps suggest that it is, in reality, only one act of a great drama. We should not mistake an episode for the main event. The Reformation soon reached its full expression in dividing Christendom. Geographically it culminated in 1648, at the treaty of Westphalia. By the philosopher it will ever be contemplated with unalloyed satisfaction, for it asserted as its chief doctrine the right of the human mind to judge for itself, a doctrine so unspeakably precious as to make of no account the inconveniences which arise in its practical application from the continual multiplication of sects.

Influence of the Christian Church on European civilization.

In the history of the European, from the time of the Emperor Constantine to the eighteenth century, the ecclesiastical element so greatly preponderates as to constitute its almost essential feature; and, after all, it is impossible to do justice to the effects which ensued on the establishment of Christianity, and its adoption by the white man as his religion. The civil law exerted an exterior power in human relations; this produced an interior and moral change. The idea of an ultimate accountability for personal deeds,

of which the old Europeans had an indistinct perception, became intense and precise; the sentiment of universal charity was exemplified not only in individual acts, the remembrance of which soon passes away, but in the more permanent institution of establishments for the relief of affliction, the spread of knowledge, the propagation of truth. Of the great ecclesiastics, many had risen from the humblest ranks of society, and these men, true to their democratic instincts, were often found to be the inflexible supporters of right against might. Eventually coming to be the depositaries of the knowledge that then existed, they opposed intellect to brute force, in many instances successfully, and, by the example of the organization of the Church, which was essentially republican, they showed how representative systems may be introduced into the state. Nor was it over communities and nations that the Church displayed her chief power. Never in the world before was there such a system. From her central seat at Rome her all-seeing eye, like that of Providence itself, could equally take in a hemisphere at a glance, or examine the private life of any individual. Her boundless influences enveloped kings in their palaces, or relieved the beggar at the monastery gate. In all Europe there was not a man too obscure, too insignificant, or too desolate for her. Surrounded by her solemnities, every one received his name at her altar; her bells chimed at his marriage, her knell tolled at his funeral. She extorted from him the secrets of his life at her confessionals, and punished his faults by her penances. In his hour of sickness and trouble her servants sought him out, teaching him by her exquisite litanies and prayers to place his reliance on God, or strengthening him for the trials of life by the example of the holy and just. Her prayers had an efficacy to give repose to the soul of his dead. When even to his friends his lifeless body had become an offense, in the name of God she received it into her consecrated ground, and under her shadow he rested till the great reckoning day. From little better than a slave she raised his wife to be his equal, and, forbidding him to have more than one, met her recompense for those noble deeds in a firm friend at every fireside. Discountenancing all impure love, she put round that fireside the children of one mother, and made that mother little less than sacred in their eyes. In ages of lawlessness and rapine, among people but a step above savages, she vindicated the inviolability of her precincts against the hand of power, and made her temples a refuge and sanctuary for the despairing and oppressed. Truly she was the shadow of a great rock in many a weary land!

The civilization of the European, so far as it has yet advanced, has been accomplished by the agency of many different causes, foreign and domestic; but among all these, the institution of the Christian Church stands pre-eminent by reason of the moral power it exerted, its duration, and the social benefits it has conferred.

Out of the numberless blessings which have thus been conferred on our race by the Church, the physiologist may be permitted to select one for remark, which, in an eminent manner, has conduced to our physical and moral well-being. It is the institution of the Sabbath day. Not that this originated with, or is peculiar to the Christian faith, since, as is known to all, it dates from the remotest times, and was directly adopted from the Hebrew ceremonial. Its sanctification and enforcement by the Church was at once an object important in the highest degree in ecclesiastical polity, and a boon to all classes of men; for in whatever position of life we may be placed, it is needful for us to have an opportunity of rest. No man can for any length of time pursue one avocation or one train of thought without mental, and, therefore, bodily injury—nay, without insanity. The constitution of the brain is such that it must have its time of repose. Periodicity is stamped upon it. Nor is it enough that it is awake and in action by day, and in the silence of night obtains rest and repair; that same periodicity which belongs to it as a whole, belongs to all its constituent parts. One portion of it can not be called into incessant activity without the risk of injury. Its different regions, devoted to different functions, must have their separate times of rest. The excitement of one part must be coincident with a pause in the action of another. It is not possible for mental equilibrium to be maintained with one idea, or one monotonous mode of life. There is a necessity even for men of great intellectual endowments, whose minds are often strained to the utmost, to fall back on other pursuits, and thus it will always be that one seeks refuge in the pleasures of quiet country life, another in foreign travel, another in social amusements. Pitt sought a relaxation from the cares of politics in the excitement of the chase; Davy found a relief and consolation in the rod and line; and among men whose lot is cast in the lowliest condition, whose hard destiny it is to spend their whole lives in the pursuit of their daily bread, with one train of thought and one unvarying course of events, the same principle imperiously applies. It is often said that the pleasures of religion are wholly prospective, and to be realized only in another world; but in this there is a mistake, for those consolations commence even here, and temper the bitterness of fate. The virtuous laborer, though he may be ground down with the oppressions of his social condition, is not without his relief: at the anvil, the loom, or even the bottom of the mine, he is leading a double existence—the miseries of the body find a contrast in the calm of the soul, the warfare without is compensated by the peace within, the dark night of life here serves only to brighten the glories of the prospect beyond. Hope is the daughter of Despair. And thus a kind Providence so overrules events that it matters not in what station we may be, wealthy or poor, intellectual or lowly, a refuge is al-

The Sabbath day.

Necessity of periods of rest.

ways at hand, and the mind, worn out with one thing, turns to another, and its physical excitement is followed by physical repose.

Influence of public worship.

By the enforcement of the observance of the Sabbath the Church gave effect to this providential system of physical and mental relief. I have already said that her chief strength lay in this, that she concerned herself with the common man, who never in the world's history before had had any to watch over or to care for him. She humanized him by the devotional solemnities of a sacred day—a day of entire relief from toil. Ignorant and rude though he might be, it was not possible for him to enter her hoary temples without being made a better man. The atmosphere of rest, the twilight streaming through the painted windows, the prayer in an unknown tongue, the slow chanting of old hymns, or the swelling forth of those noble strains of music, which, once heard, are graven in remembrance forever—these she had made, with more than worldly wisdom, the elements or incidents of public worship. She gratified the manly sense by asserting before her altar the equality of all men, by making the vain and transitory gradations of society disappear, and by teaching the rich and the poor, the great and the humble, their common dependence on the mercy of God. Under her powerful influence, inarticulate Nature, as if spellbound, seemed to acquiesce in the tranquillity of the Sabbath day, and to assume an air of rest. In the cottage they rose at a later hour. The father cleansed himself with more than usual care, and, if it was the custom of his country, shaved his face, perhaps sadly neglected in the intervening week, and dressed himself in his better clothing. His honest pride found a gratification in the neatness of his wife and children. His table was more bountifully supplied, his heart humanized by the grateful relief from labor, and the society and converse of those dearest to him. Physically and mentally he rests, and by that rest is enabled to sustain the cares of a life of toil. It is not without a reason which we may turn to our profit, that the Scriptures have placed upon lasting record that the Great Head of the Church has taught us both by precept and personal example how to use this day; and that, for the sake of the many generations of laboring and weary men who were to follow him, he inflexibly resisted every attempt at encroachment upon it by the grim bigots and hypocrites of his times.

The civil law.

Though Rome did little for Europe in the production of knowledge, she thus served its interests well in the most vital respects. She gave it her system of law and her religion. With the introduction of Roman usages among barbarians came the Roman law, modifying or abrogating the existent imperfect polities. To a considerable extent, its spread was due to the influence of the ecclesiastics and the wants of the rising municipalities.

The influence exerted by the Roman empire on the social condition of Europe in the two particulars to which reference has been made, the introduction of the civil law, and the establishment of the Christian Church, occurred in the period of its decline, and was therefore contemporaneous with the spread of Mohammedanism through the north of Africa, and the occupancy of Spain by the Arabs. To a very considerable degree, the practical character which European thought has exhibited in later centuries is to be attributed to the Arabians, who have justly been termed the founders of physical science; for though, through them, the literature of Greece was introduced into Western Europe, the writings of Aristotle, for example, being made known through an Arabic translation, they imparted to what they thus gave their own particular impress. Being the first founders of organized institutions for the cultivation of medical pursuits, answering completely to our modern medical colleges, they attached to those professional studies their own peculiar methods. It was therefore in this way that botany and chemistry were particularly cultivated, because they were regarded as the foundation of Materia Medica. Humboldt remarks, that while the Europeans have been disposed to connect the physical sciences with theology, the Arabians connected them with medicine, and that through their medical colleges they ruled the Christian schools, who looked up to Avicenna and Averroes as the great authorities on these subjects. The most important applications of the mathematical sciences to the purposes of life were made by the Arabs. Of this it is sufficient to mention the introduction of the notation of arithmetic and many instruments of navigation, the former not only furnishing an invaluable aid in the computations required by the wants of a commerce which reached from the north of Europe to Madagascar, and from the Atlantic islands to China, but, what was of even more importance, in the progress of mathematical science itself, the latter through the aid afforded in astronomical observations permitting the successful accomplishment of voyages in seas which even to that time had been little frequented.

Influence of the Mohammedans on Europe.

The Arab schools.

It would extend this chapter unduly if we were to enter into any detail of the special contributions of the Arabs to the stock of European knowledge. It may, however, be briefly remarked, that we owe to them our system of universal arithmetic, and even the title under which it now passes, algebra. Their discovery of the strong acids, nitric, sulphuric, and also aqua regia, constitutes an epoch in chemistry. The cultivation of that science also was stimulated in no small degree by their attempts at the transmutation of the baser metals into gold, and the discovery of the means of indefinitely prolonging life—the philosopher's stone and the elixir vitæ. In the science of optics, the work of

Arab discoveries.

Alhazen on refraction demonstrates their cultivation of the methods of physical experiment and observation, and their application of the pendulum to the measurement of time is even yet acknowledged to be the most perfect contrivance for that purpose.

In estimating the value of the influence which the Mohammedans exerted upon the European mind, we recognize its specific similarity to that which, more than a thousand years before, had been communicated from the schools of Egypt under its Macedonian kings, and even, still centuries before that, at the time of the opening of the Egyptian ports. In all three cases the tendency imparted was to the cultivation of the physical sciences, then in their infancy, and thereby to the increase of the material power of the race. In a very short time, inventions which have been of the utmost importance made their appearance, such as gunpowder, the mariner's compass, and various optical instruments. It is of no moment whether these were introduced by the enterprise of the Arabs from Asia or whether they were of indigenous origin; there can be no doubt that the intellect of Europe had reached that peculiar phase, and the tendency of thought was in that particular direction that, even if these discoveries had not been communicated from abroad, they would very soon have been made at home.

The Mohammedan attacks on Europe were retaliated by the Crusades.

The Crusades.

These strange wars, into which the white race plunged, were instigated by the Roman government toward the close of the eleventh century, and were followed by consequences which their projectors never expected. They precipitated barbarian Europe upon Asia, under the pretense of rescuing the Savior's tomb from the infidel, but in reality to keep back the threatened tide of Saracenic invasion, and to divert from Italy the restless military spirit that was every where engendering. No other motive than the one thus ostensibly put forth could have brought the ferociously independent hordes of Europe to act together. It had been well if, in ancient times, the emperors had been in possession of so useful a device; it might have saved the city from some sieges and sacks. As it was, the turbulent stream was thrown upon the Byzantine monarchs to their utter perplexity. The Saracens received it with amazement. The ostensible causes which had set in motion such a countless rabble of stupid barbarians were absolutely incomprehensible by them. In their invasions of Europe they had carried the light of such science as they possessed, but in this counter invasion of Asia they were repaid with the most besotted ignorance.

Influence of the Crusades on Europe.

The Crusaders found that the infidel they had come so far to encounter without provocation was valiant and polished, in many cases merciful and just. Their ideas of the Asiatics underwent a great change after they had been in contact with

them for a time. Those who lived to return to their homes from the successive expeditions spread abroad a more enlarged and correct conception of Oriental countries, events, and men, the influence of which was not lost to civilization. In his imprisonment in the fortress of Dierstein, the lion-hearted Richard of England doubtless reflected that there was more honor in the infidel Saladin than in many a Christian king. It has not escaped the observation of historians that the frequent communication which these events established between all parts of Europe and the Italian court served often to disturb the sentiment of piety. The visitors at Rome saw things which had been better concealed. Their unaffected simplicity was shocked by the dissipation and immoralities in high places. They carried the shameful story to their homes.

Advantages derived from the Crusades.

Among the unexpected and lasting advantages arising from the Crusades, not one of which had been contemplated by the Italian court, may be enumerated more enlarged and liberal views of foreign nations, and the importation of Asiatic discoveries. From the remote parts of that continent embassadors came to Italy, and enterprising European travelers, like Marco Polo, wandered in return all over it. In this manner the knowledge of the mariner's compass was obtained. From having learned to employ their ships in warlike expeditions, the Western nations were induced to enter on that career of maritime commerce which soon led them to the discovery of America and the doubling of the Cape of Good Hope, and which, in these times, constitutes the chief feature of their life. Trade, which until then had been overland or terrestrial, became maritime—a change important to the last degree, since it eventually gave rise to the prodigious development of manufacturing industry. Heavy masses of goods can never be transported by caravans, though they can easily in ships. The geographical value of countries was changed. Egypt, for instance, lost her position, not to be recovered again until the invention of the locomotive, which will restore land-transport to its former state. Wealth poured into the maritime states, and markets were sought for all over the globe. Moreover, the separate principalities and kingdoms were taught to act in unison, and the idea of Europe—united Europe—was made manifest. As a present advantage was realized the downfall of the feudal system, and, as a direct consequence thereof, a redistribution of the population. To this system, in its flourishing period, some have been disposed to impute many benefits—that it originated our domestic manners, gave birth to the sentiment of loyalty and honor, cherished independence, and elevated the female sex; but these are misconceptions or exaggerations. In the last particular, the advancement of women, the merit is strictly due to the Church; for, had there been no other reason, the universal prevalence of Mariolatry throughout Christendom, by diffusing a most accept-

able and even adorable image of female loveliness and virtue, would have led to that result.

Discovery of America by the Spaniards.

But far exceeding the Crusades in effect, more distinct in its origin, since it directly resulted from the tone of thought which the Arabs had introduced, lasting in the influence that it has exerted, and will forever exert on the destinies of the white race, was the discovery of America by the Spaniards in 1492. This continent, four hundred years before, had been visited repeatedly by the Icelanders and Norwegians; but the shores they discovered being less hospitable and less tempting, their expeditions unsupported by a powerful home government, and the results little attractive, the very remembrance of them seems almost to have passed away. Had it not been for the magnetic needle, and other instruments of navigation introduced from the East, the passage of the tropical Atlantic could never have been accomplished, and probably would never have been attempted. Moreover, we must not overlook the fact that the rapid conquests of the Saracens, and even the Crusades themselves, had introduced a largeness of conception, and had familiarized the public mind with undertakings to be accomplished in regions that were very remote. The successful return of Columbus from his first voyage found all Europe ready to rush into Western enterprises, and this event may be truly regarded as a grand epoch in the history of the white race, since it more than quadrupled the geographical surface over which they might spread, and presented to their unmolested occupation climates from the equator to the extreme north and south.

Colonial empire of Spain.

In the prodigious emigration that ensued, Spain led the way, and did so to her ruin. In vain she received and scattered over Europe the wealth of Mexico and Peru; she gave in exchange for it what was to her of infinitely more value—the most enterprising and bravest of her people. The drain of this class produced an effect from which she has never recovered. It left her without energy and imbecile. In vain shè founded a greater, and, for the time, more prosperous colonial empire than history has ever recorded, carrying her influences through a large part of South and much of North America, from the Atlantic to the Pacific Ocean. Her emigrants, unable to withstand the influences of a tropical climate, and intermarriages and connections with the native races among whom they were thrown, soon lost the enterprise that had once distinguished them, and the descendants of the Spaniard in America exemplify at this day the universal imbecility that is exhibited in the mother country.

The fall of the Spanish power.

In her pursuit of the wealth of America Spain was a fearful oppressor. Bartholomew de las Casas, the Bishop of Chiapa, to use his own expression, charged her "before the tribunal of the

Universe," with destroying more than fifteen millions of natives during his time. "The acrimony of his style was complained of, but the fact was never denied." No nation can practice such atrocities with impunity. The day of reckoning may be a little postponed, but it brings its inexorable verdict in the end. The broad hand of an overruling Providence is at last plainly discovered, imposing with an unerring justice the penalty of national crime. There is no need for God to hasten, he has the centuries and eternity to work in. Even now, is not the Spaniard in the hands of an avenger for the Indian blood that cries for retribution from the silver mines of Mexico? For the failings of the individual there is mercy, but in the ways of eternal justice no mediator is provided for the crimes of society. There is an inflexible recompense of good for good and evil for evil.

The later mental changes in Europe.

The step which the intellect of the white man has made since the Reformation is very strikingly discerned by comparing the natural philosophy of the fifteenth with that of the nineteenth century. Its passage to its present condition has been marked by a continual casting away of the marvelous. It is almost impossible for us now to realize the fictions which occupied the minds of our predecessors. To penetrate "the secrets of nature" is with us a metaphorical expression; with them, a portentous and solemn reality, most readily accomplished by the help of familiars and imps, whose services might be secured by forbidden enchantments. The laboratory of an alchemist was ill furnished which did not possess in the shape of an ungainly and deformed dwarf such an aid, and who, if not the incarnation of a devil, was at least possessed by one. Operations for the discovery of the philosopher's stone, the powder of projection, and elixir of life, were necessarily commenced by exorcism, invocations, and a favorable aspect of astrological combinations. There were seven planets, and also seven metals, and the guiding spirits which resided in the former exercised their influence over the latter, communicating to them their specific virtues. The expressions have lost their significance, though they have descended to our times, when we call a certain metal mercury, and a salt lunar caustic.

As Mr. D'Israeli, in his "Curiosities of Literature," remarks, whoever had been a witness of the miracles of these philosophers might well be prepared to believe any of their declarations. He who had visited the dark chamber of Baptista Porta, and seen with his own eyes its fairy but inverted landscapes, its fields, and rocks, and rivers, and the moving forms of men and animals in their proper colors and indescribable charm of light and shade, the clouds and sky, the magical spectres of things which the fingers could not grasp, a perfect but artificial day-dream, might surely feel justified in also believing in the enchanted mirror upon which.

if a man looked, he would find reflected all the future events of his life. He who had seen the phantasmagoria cast upon smoke in these mysterious laboratories, now so little that the eye could scarcely discern their form, and now expanding to a gigantic stature and rushing forth, was duly prepared to credit the legends of brazen men who could speak and even prophesy, nay, whose limbs would continue to grow unless the demon that possessed them was cast out. A vial of that which we call ammonia, the mere smelling of which can recall one from a swoon, was a very fair earnest of the elixir of life. No prodigy was too great to be believed. As in dreams, nothing was too impossible, nothing too contradictory. Men who could make themselves invisible even without the romantic aid of a ring; incombustible sages who could wash themselves in melted copper, and sit at their ease in flaming straw; alchemists in possession of the philosopher's stone, but their stomachs as empty as their bellows; monks carrying about fairies shut up in glass vials, into which they had been decoyed by distilled dew; salamanders which had been engendered in a fire maintained without ever going out for forty years; a rain in Egypt in which there fell multitudes of little men of less than one span, clothed in black garments, and with mitres like bishops: these were all facts in the philosophy of that day. The explosions and choke-damp of mines were not disentangled from spectres and faces of abominable appearance which had been seen in those subterranean solitudes by numberless witnesses until the dawn of pneumatic chemistry. The palingenesis, or resurrection of roses and apparitions of flowers, so acceptable in doctrinal theology, continued to be received until crystallography was cultivated. These wonders have all passed away.

Gradual disappearance of credulity.

The character which marks this change is the gradual dropping of mystery and the supernatural. The same career is followed from infancy to maturity, both in the individual and in society.

It is not necessary to pursue any further this historical outline. It would bring us to events which can scarcely be spoken of with correctness and impartiality, on account of their nearness to our own times. Here, therefore, we may pause, to collect such inferences and present such reflections as the facts we have offered suggest.

Physiological change of Europeans.

It may, then, be observed, that the old white inhabitants of Europe were not able to commence their civilization from their own interior resources, but were thrown into that career by the example and aid of a more southern and darker people, whose climate was more favorable. The artificial change which spread by degrees over Europe, through the introduction of more comfortable modes of life, at last compensated for the natural climate defect, and the European entered on the course of advancement, undergoing, as we have seen in the last chapter, a physical as well as a mental change.

Contemporaneous with the commencement of this physiological and psychical change was the introduction of a method of record by writing, which at once aided, in the most marked manner, the dissemination of this improving condition, especially by leading to the consolidation of society through the introduction of durable systems of law. By this, the influence of men and of generations was indefinitely extended. The opinions and thoughts of those times have actually, in many instances, descended to us. Elsewhere we have dwelt on the fact that these effects in the progress of humanity are foreshadowed and illustrated in the course of individual development. A high psychical condition demands as its essential, both in the individual and in the race, a mechanism of registry.

Result of the introduction of writing.

From the preceding imperfect narration we may moreover gather that the progress of civilization in Europe has not been in the way of a diffusion from a central point, but that there has been a shifting of the centre of intellect. For a length of time it was in Greece; then it passed to Italy; in our times it is still more to the west. In a philosophical respect, the result of Mohammedanism on Europe has been, through the introduction of physical science by the Arabians, to coalesce the centre of intellect and the centre of force. Henceforth upon that continent physical power must be subordinate to intellectual.

Centre of intellect of Europe.

In this we see what is the true interpretation of the influence which Mohammedanism has exerted on Europe—an influence which, though popularly, is very unworthily represented as an occupation of Spain for a few centuries and the capture of Constantinople. In truth, it was of a far higher and very different order. The Koran of the Arabians failed to make its way through Europe, but it was very different with the physical science of the Arabians. Its spread was the true foundation of modern national power, for it at once occupied itself with the development of material resources and the introduction of useful inventions. The manner of thought it engendered lies really at the basis of the great intellectual controversy of our times. The translation of the centre of intellect from Italy to the West is the legitimate issue of the Moorish invasion of Spain.

Effect of Mohammedanism on the centre of intellect of Europe.

As regards that propensity to the decomposition of every thing into its constituent elements which is the tendency of the European, though doubtless it has its disadvantages, we are not to suppose that it leads of necessity to an intellectual chaos. Those authors who view with dismay our present state, who represent us as though, both in polity and religion, we were crumbling to pieces, and that the multiplicity of opinions and sects, which are ever on the increase, is the precursor of a universal anarchy, have never duly considered that out of such a state it is possible in an instant for fixed

Result of the analytical tendency of the European mind.

principles of order to emerge, and this not by any process of compression or suppression, but spontaneously in the natural course of events. In the outset of this brief historical description I have alluded to the adoption of alphabetic writing in Europe as a signal illustration of the mental peculiarity of the inhabitants; this may also serve to make clear the paradoxical assertion that systems founded on indefinite subdivision may suddenly free themselves from complexity and become simple and perspicuous. On a superficial consideration of the thing, one might imagine that to decompose articulate sounds into their constituent syllables, with a view of representing those syllables by symbols, would be attended with a prodigious complication, and that such is the case the Chinese have found, who have pursued this plan in its details until it is said that their alphabet contains 80,000 letters; but still more would it be supposed that if those syllables were in their turn decomposed into their constituent parts, the required elements would be utterly unmanageable by reason of their number, and the art of writing utterly impracticable; yet do we not find, on the contrary—and it may be an instructive lesson to us—that when the decomposition is thus pushed to its extreme, instead of myriads of characters being required, as we might have plausibly expected, an alphabet of 20 or 30 letters is all we want? The state of opinion in Europe is illustrated by the state of writing in China.

In view of the facts presented in this and the foregoing chapter, we may come to the general conclusion that the extremes of humanity, which are represented by a prognathous aspect and by a complexion either very dark or very fair, are equally unfavorable to intellect, which reaches its greatest perfection in the intermediate phase; that, even in the condition which was presented by the inhabitants of Europe three thousand years ago, no advance in civilization was possible, save by first accomplishing an absolute physical change in their constitution through modifications in their habits of life equivalent to a true climate change—a preparation for a higher mental development by an amelioration of their condition of life.

Conditions of European improvement.

The civilization of the European could never have been accomplished save by preparing the way through such a physical change. It followed that change in the manner that effect follows its cause. Its incident was the transformation of the fair race which then occupied all Europe to another of a darker hue; the extinction of the disappearing people not being accomplished by such means as an extermination, after the manner in which the North American Indian is dying out, but by a slow and true metamorphosis into another form.

Advance in civilization takes place during such a metamorphosis. Asia, which, at an early period, must have exhibited a mental development of great rapidity, has long ago become stationary.

Stationary condition of Asia.

In her physical life there is no change, and hence none in her intellectual. Her wandering central tribes encamp on the steppes in the same felt huts that their ancestors did two thousand years ago; her southern people never vary their customs. That which, in a philosophical respect, is the most important condition, domestic economy, has undergone no kind of modification.

But with us, how different! The hardships of life have to a very great extent been removed, and we are familiar with a degree of comfort to which our predecessors were wholly strangers. Not that we have been freed from all trials; it has only been an exchange of bodily sufferings for mental anxieties. Our higher condition has created new wants and new sources of pain.

Advantages arising from an analytical and mental constitution.

With the transformations through which, as a race, we have passed, and with the assumption of that analytical mental character to which I have referred, there has been gained a capability of indefinitely modifying our state, and, therefore, of improving it. It is this which pre-eminently distinguishes the European; that whatever scientific discovery he makes, or whatever invention occurs to him, he forthwith applies it to economic advantage, and is thereby perpetually impressing a change on his own state. In this respect, even a single generation often suffices to show the advances which are made. We have only to recall the greatly improved means of locomotion; the instantaneous transmission of intelligence through many thousand miles; the development of industrial art, and the rendering available mechanical powers for many new purposes, which have been achieved in less than a single century. Nor does there seem to be any possible limit to human advance in this path.

Since thus the mind of the European is essentially analytic, his advance in civilization, as it were in a geometrical progression, is the necessary consequence thereof. If we examine his career in subordinate particulars, it illustrates equally his mental physiognomy; it is the same whether we look to his passage in philosophy, science, politics, or religion. If I may be permitted without offense so to say, his divergence from a single form of faith, the springing up of those numberless denominations and sects which constitute the most observable feature of his present religious state, is a result which he can not help, for it is the consequence of his organization. Things which were possible in the eighth century had become impossible in the new state of the sixteenth. And so, too, it is in his political relations.

Herein consists the superiority of the analytical over the synthetical mind. To the work of him who pulls to pieces there is no end, but he who puts things together comes to an end of his task.

INDEX.

A.

Abducentes, 334.
Aberration, chromatic and spherical, 386.
Abrupt and gradual impressions, 483.
Absorbed material, course of, 109.
Absorption, forces of, 110; by blood-vessels, 49, 84, 102; nutritive, 84; double mechanism for, 84; in plants, 86; summary of, 108; by lacteals, 84, 86; by lungs, 163; by general surface, 98; by skin, 98, 241; two kinds of, 86; interstitial, 98; selecting power in, 99.
Abyssinian, 577.
Acid, hydrochloric, use of, 52.
Activity of the brain depends on arterialization, 326.
Affinity for tissues the cause of circulation, 133, 147.
Africa, influence of Europe and Asia on, 593; prospective civilization of, 597; inhabitants of, 577.
Agassiz on origin of nations, 568.
Age, influence of, 61, 172; old, 545.
Agents, external, influence of, on man, 567.
Agony, final, 562.
Air, introduction of, 160; expired per minute, 168; passages, evaporation from, 186.
Air-cells of lungs, 159, 160.
Albumen, 29; transformation of, into fibrin, 100; quantity of, 121.
Albuminose, 61, 64.
Alcohol, use of, in supporting heat, 20; effect of, 182, 406.
Alexander, expedition of, 620.
Alexandria, library of, 624.
Aliment, necessity for, 10.
Allantois, 531.
Allotropism of bodies, 188; decay depends on, 244.
Alpha and Beta lactic acid, 75.
Alphabetic writing, 358.
Alternate consciousness, 330.
Alternation of generations, 514, 537.
Amber, trade in, 619.
Amelioration of negro, 578.
America, discovery of, 632; spread of Christianity in, 598; Indians, 575.
Amnion, 530.
Amphibia, blood of, 121.
Analogy of spinal and ventral cord, 308.
Analytical mind of European, 592; advantages of, 618, 635, 637.
Animal, capillary circulation of, 133; heat illustrated by locomotive, 187; makes fat, 247; motion, 431.
Animal kingdom, subdivisions of, 176.
Anterior roots of spinal cord, 296.
Anthropomorphism, 286.
Antrum duodeni, 61; pylori, 61.
Ants, habits of, 605.
Aplysia, 280.
Apparitions, 402.
Appendix vermiformis, 63.
Approach of sleep, 532.
Aqueous humor, 386.
Arabs, discoveries of, 629; influence of, 629.
Araucanians, 598.
Arc, automatic, 277; cellated, 278; influential, 282; commissured, 279; multiple, 278; registering, 281.
Aristotle, 620.
Arm, 580.
Art, contributions of Asia to, 595.
Arteries, coats of, 140; contractility of, 141; structure of, 140.
Article of death, 411.
Artificial larynx, 355.
Ascaris acuminata, 524; nigrovenosa, 524.
Ascent of sap, causes of, 87.
Ascherson on use of fat, 101.
Asia, stationary condition of, 636.
Asiatic contributions, 595.
Asterias, nervous system of, 279.
Astrology, 178.
Atmosphere, action of, on plants, 464, 482.
Attraction, capillary, 104.
Auditory Mechanism, general view of, 376.
Auditory muscles, estimate of contraction of, 367; nerve, 361.
Auricles of heart, 138, 146.
Australian, 563; forests, 474.
Automata, insects are, 609.
Automatic arc, 277, 283; registering, 281.
Awakening, 553.
Axmann on nerves, 263.

B.

Bacon, Roger, 625.
Balance between heating and cooling, 186.
Barbarism, 604.
Barral on food distribution, 39.
Basilar view of skull, 584.
Beaumont on food, 66.
Becquerel, table from, 33.
Bee, formation of fat by, 248.
Beef, digestibility of, 65.
Bell, discoveries of, 259, 298, 318.
Beneké on hospital diet, 35.
Bernard on digestion, 76; on fat, 71; on saliva, 196; on liver-sugar, 208.
Bernouilli, principle of, 90.

Berzelius on lactic acid, 75; on perspiration, 240.
Bibra, Von, on brain fat, 274.
Bidder on albuminates, 39; on section of pneumogastric, 54.
Bidder and Schmidt on intestinal juice, 69; on bile, 70; table by, 70.
BILE, secretion of, 70, 110, 202; composition of, 204; formed from venous blood, 110, 303; sources of, 202; aids in introducing fat, 91; spiral course of, 201; change by retention of, 205; period of maximum flow of, 205; not formed in the liver, 206; manner of removal of, 206.
Bipolar nerve-cell, 264, 268.
Bird, digestive tract of, 58; respiration and heat of, 159; talking, 352.
Bishop of Chiapa, his accusation, 632.
Black pigment, 387.
Black Sea trade, 619.
Blastodermic vesicle, 524.
Bligh on Pelagians, 580.
BLOOD, 111; properties of, 112; composition of, 112; total amount in body, 113; coagulation of, 113; buffy coat of, 114; changes produced in by respiration, 120, 126, 134; excretion of carbonic acid from, 126, 167; changes of color of, 169; density of, 169; salts of, 124; gases of, 125; functions of constituents, 125; course of, 134; distribution of, 144; glandular change of, 190.
Blood of spleen, 212.
Blood-cells, form of, 115; constitution of, 118; origin of, 94, 115; destruction of, 209; increase of, 125; diminution of, 126; short life of, 127; changes in form, 117; cell wall of, is fibrin, 117.
Blood, colorless, corpuscles of, 115, 120.
Blood crystals, 119.
Bloodletting, reduction of temperature by, 184.
Blood-vessels, origin of, 528.
Blumenbach's method of examining the skull, 582.
Bone, 253; sources of, 257; composition, 254; growth of, 256.
Bonito, 177.
Boussingault on expiration, 39; on gum, 72; on fat, 39, 229.
Bovista giganteum, 88.
Bowman on kidney, 223.
Brahmin, 573.
Brain, 313. See Cerebrum and Cerebellum.
Brazen men, 634.
Bread, 33; use of butter on, 34; making of, illustrates digestion, 78; sets free alcohol, 79.
Breath, the first, 148.
Breathing, act of, 156.
Bright on pancreas, 71.
Bronchial tubes, 159.
Brown-Sequard on muscle, 443; on rigor mortis, 453; on spinal cord, 299.
Bruchium, gardens of, 621.
Bud, its nature, 469.
Budding, 469, 535; reproduction by, 495, 535.
Buffon on infancy, 539.
Buffy coat, 114.
Burning lenses, 461.
Butter, making of, 31.

C.

CALIFORNIANS, 576.
Calorific hypothesis of vision, 599.
Calorifacient digestion, 63.
Camelopard, 491.
Camera obscura, 381.
Camper's method of examining skulls, 581.
Canaliculi, 253.
Canals, semicircular, 375.
Cape of Good Hope, discovery of, 34, 631.
Cape Hyrax, stomach of, 59.
CAPILLARY VESSELS, 39, 141, 160; movement of blood in, 145; of muscle, 459.
Capillary absorption, 103; attraction, 104; propositions respecting, 105; motion, 131.
Capillary circulation, 142; phenomena of, 145; in acardiac fœtus, 144; in asphyxia, 145; local excitement, 144.
Carbohydrates, 71; turn into fat, 81; make up deficit of albumen, 39.
Carbonic acid excretion, 164; sources of, 164, 252; introduces oxygen, 165; decomposed by light, 461.
Carcinus mænas, 510.
Career of man, 612; of organic form, 456.
Carnivora consume themselves, 36; fibrin of their blood, 123; find fat in their food, 248.
Carp, lung of, 157.
Carpenter on nervous system, 259; on sensorium, 319; on analogy between spinal and ventral cords, 307; on generation, 537.
CASEIN, 30, 31, 231; pre-exists in plants, 36; changes into fibrin, 35; dissolves phosphate of lime, 35.
Castle building, 330.
Catamenia, 519.
Caudate vesicles, 264.
Causes of sleep, 552.
CELLS, primordial, 458; simple and nucleated, 492; animal, 496; circulation in, 132.
Cells of blood, 116; uses of, 129; numbers of, in different animals, 121.
Cells of kidney remove unoxidized bodies, 223.
Cells in lungs, 159.
Cells, nerve, 264.
Cellulose, 71.
Centre of intellect, 635.
Centres of nerves, 290.
Centripetal and centrifugal fibres, 265.
Cephalic ganglia, 271, 607.
CEREBELLUM, 322; development of, 314; experiments on, 323; structure and function of, 322.
Cerebral sight, 401.
Cerebro-spinal fluid, 326.
CEREBRUM, structure of, 317; development of, 314; aspects of, 316; tracts of, 318; ganglia at base, 319; weight of, 325; atmospheric pressure on, 326.
Cheese, making of, 31.

Cheselden's case of cataract, 419; on the ear, 365.
Chest, type of, 161.
Chilians, 576.
Chimpanzee, 581.
Chinese, 574; writing, 636.
Chitin in wings of insects, 71.
Chlorine and hydrogen, 471.
Cholepyrrhin, 124.
Cholera, effect of, 22.
Cholesterine, 275.
Chorda dorsalis, 528.
Chorion, 523; changes in, 525.
Choroid coat, 384; function of, 394.
Chossat on inanition, 178, 243.
CHRISTIAN CHURCH, 626; spread of, in America, 598.
Chromatic aberration, 386.
Chronometer, illustration of heart by, 140.
CHYLE, 53; absorption of, 87; causes of the flow of, 89; composition of, 92; corpuscles, first appearance of, 94; action of water and acetic acid on, 94.
Chyme, 53.
Cilia, 431.
Ciliated animacule, 432.
CIRCULATION, 145; objects of, 111, 134; changes during, 126; course of, 134; in plants, 132; in lower animals, 135; action of heart in, 138; sounds of heart in, 139; nervous influence on, 140; fœtal, 531; placental, 527; portal, 134; connection of parts by, 112; dependence of, on respiration, 133.
Civil law, 628.
Civilization, effect of climate on, 599; compared with barbarism, 604.
Classification of natural history, 506; of skulls, 586.
Climates, botanical, 481.
Clock, illustration from, 485.
Coagulation of blood, 113.
Cochlea, 364, 368; comparative anatomy of, 373.
Cœliac axis, ramifications of, 49.
Coinage, introduction of, 620.
Cold-blooded animals, 172, 176.
Coleridge on dreams, 556.
Colladon on diving-bell, 366.
Color, origin of, 589.
Colored rays, effect of, 461.
Colostrum, 225.
Combustion, artificial, 17; organic, 17, 18.
Commerce, origin of European, 619.
Comminution instruments, 40.
Commissures, function of nervous, 280.
Comparative history, 612.
Compartments of ruminant's stomach, 60.
Complemental air, 165.
Complexion of man, 571, 572.
Conception, 530.
Condensing action of membranes, 155.
Condition of dreams, 558.
Condorcet on dreams, 556.
Conductibility in nerves, 265.
Conferva, 495.
Congelation, perpetual, 473.
Conjugation, modification of, 515.
Consonants, 356; explosive and continuous, 357.
Constant temperature, problem of, 176.
Constituents of plants, sources of, 463; of the blood, functions of, 125.
Contarini, Cardinal, on circumnavigation, 625.
Contractile fibre-cells, 435.
CONTRACTILITY of muscle, 442, 449; nature of, 442.
Contraction, hypothesis of, 451; by water, 451; by touch, 452; after death, 444.
Control of heat by nerves, 186.
Converging media, 381.
Cooling agencies, 184.
Cord, spinal, 294; conduction by, 299.
Cornea, 384.
Corpuscles, of milk, 225; of fat, 246; of blood, 116; origin of, 101, 115; colorless, 93, 115; of chyle, 93, 143; proportion of, 125.
Cotyledons, 526.
Couch on metamorphosis, 510.
Course of the bile, 202.
Crab, edible, 510.
Cranial nerves, 333.
Creatine, 447.
Crevice, passage of water through, 105.
Crime, tendency to, 543.
Crises, change by, 148, 484.
Crus cerebri, 314; cerebelli, 314.
Crusades, 630.
Crystalline lens, 386.
Crystals of blood, 119.
Cutaneous absorption, 98.
Cuvier on organisms, 466.
Cycles of progress, 512.

D.

DALTON on corpus luteum, 522; on diffusion, 152.
Daubenton on skull, 580.
Davy on animal heat, 178; on meconium, 203; on protoxide of nitrogen, 412.
Deafness in diving-bell, 366; partial, of inferior animals, 377.
Death, 560; from accident and old age, 561.
Decay, 243.
Deception, 404; of touch, 421.
Deleau on the voice, 356.
Descartes on insects, 609.
Descent of sap, causes of, 87, 132.
Despretz on animal heat, 182.
Deutencephalon, 292.
DEVELOPMENT, 505; of the ear, 378; of the eye, 380; of muscle, 440; geometrical modes, 447; of bird, 35; of heart, 135.
Diaphragm movements, 161.
Diastose salivaire, 45.
Diet, 34.
Differences in men, 563.
DIFFERENTIATION, 500; causes of, 502; influence of heat on, 503; epochs of, 504; defined, 511.
DIFFUSION of gases, 152; force of, 153, 156; general facts of, 156; effect of, 162.

Diffusion of influence in granular nerve material, 268.
DIGESTION, nature of, 16, 40, 52, 63; object of, 61, 66; histogenetic, 63; calorifacient, 63; is mechanical and chemical, 57; double, 46; processes of, as insalivation, 40, 46; deglutition, 46; passage into duodenum, 52, 67; passage along intestine, 67.
Digestion, artificial, 52, 54.
Digestion of gum, 71; of cellulose, 71; of starch, 72; of sugar, 72; of fat, 76; intestinal and stomach, contrasted, 81.
Digestive tract, divisions of, 48; of insect, 58; of various animals, 59; juices, their organic ingredient, 77; power injured by saliva, 50.
Discs of muscular fasciculi, 436; of blood, see Cells.
Discus proligerus, 520.
Distribution, vertical, of plants, 473; of heat, 473.
Diurnal amount of air used, 166.
Diurnal variations of heat, 178.
Donné on saliva, 44.
D'Orbigny on Inca Indians, 487.
Dormouse, stomach of, 59.
Dorsal cord, 293; lamina, 527.
Double trains of thought, 329.
Doubleness of brain, 327.
Dowler's experiments, 444.
Draper, J. C., on respiration, 168, 239; on urea, 220.
Dreaming, 555.
Drowning, restoration from, 133.
Drum of ear, 364.
Duality of mind, 329.
Duct, thoracic, 90.
Ductless glands, 211.
Ducts, dotted, 498.
Dufay, law of, 104.
Dugong, heart of, 136.
Dulong on animal heat, 182.
Dumas on fat, 248.
Dutrochet on endosmosis, 106.
Dyslysin, 83.
Dytiscus, 438.

E.

EAR, structure of, 376; external, 360; action of, 359; auditory nerve of, 368; labyrinth of, 375; tympanum of, 365.
Education, effect of, 330, 543.
Edwards, Milne, on crustaceans, 488; on fat, 248.
Egg, development of bird from, 35.
Egypt, 613, 614.
Elasticity, heat of, 185.
Elective filtration, 196.
Electrical tastes, 430; currents in muscles, 443; conductors, nerves resemble, 266.
Electricity, 275.
Eleventh pair, 342.
Elixir of life, 633.
Elliptical skull, 586.
EMBRYO, 538; germinal membrane of, 525; vertebral column of, 532; vascular area of, 527; allantois, 538; circulation, 531; influence of mother, 534; size and weight of, at birth, 540, 541; viability of, 545.
Embryonic development of brain, 313; of circulating apparatus, 531; forms, 507.
Emergence of impressions from brain, 408.
Emotions, mental, 290.
Empiricism, extinction of, 25.
Endocardium, 137.
Endochrome, 493.
Endogenous generation, 496.
Endosmosis, 105, 107, 131; through films, 154; through stucco, 107; force of, 107, 153.
Enteric juice, 369.
Epencephalon, 292, 528.
Epidermis, 233; functions, 234.
Epithelium, 197, 234; cylindric, tesselated, ciliated, 197.
Epochs of globe, 481; of life, 547.
Equilibrium, conditions of, 10, 22, 560.
Erect vision, 396.
Esquimaux, 568.
Europe, primitive state of, 613.
European history, 610.
Eustachian tube, 367.
Euthanasia, 561.
Evaporation, 185.
Excretion, 213.
Exhalation by lungs, 21, 22.
Exosmosis, 106, 131.
Expectoration, 47.
Explosive consonants, 357.
Extinction of Indians, 600.
Extinctions, 484, 488.
EYE, structure of, 382; nervous mechanism of, 389, 394; accessary apparatus of, 399.
Eyeball, motions of, 401.
Eyebrows, 399.
Eyelids, 399.

F.

FABRICIUS AB AQUAPENDENTE on veins, 130.
Fæces, 83.
Fair races, disappearance of, 591, 636.
Falling, sensation of, 559.
Fasciculi of muscle, 433, 436; digestion of, 54.
FAT, 246; oxidizes gradually, 252; relation of, to bile, 207; to nitrogenized tissue, 250; in articles of forage, 229; emulsifying of, 71; produced from carbohydrates, 81; introduction into villi, 91; saponification of, 93.
Faunal groups, 568.
Feeling and touching, distinction between, 422.
Female and male compared, 546.
Fenestra ovalis and rotunda, 361.
Ferments, 45, 80.
Feudal system, 631.
FIBRIN, 30, 93, 97, 114; loss of, 52; vegetable, 33; not an effete body, 98; organization, 113; difference of, in blood and muscle, 114; variations in quantity, 122.
Fifth pair of nerves, 334.

Filtering action of glands, 191.
Filtration, elective, 196.
Final agony, 562.
Finite nature of knowledge, 289.
Fire-place, exhausting nature of, 181.
First breath, 485.
First pair of nerves, 425.
Fishes, digestion of, 60; circulation in, 135; respiration of, 150, 157.
Flame and plant, analogy between, 470.
Floral groups, 568.
Flour, 33.
Fœtus, circulation in, 531. See Embryo.
Follicles, gastric, 49, 50; varieties of, 51.
FOOD, 16, 26; sources of, 27; classification of, 27; value of, 28; different kinds of, 27, 28; of carnivora, 36; of herbivora, 36, 37; nitrogen, 27, 35; movements of, 53; adjusts temperature, 179; demand for, 179; allowance of, 11; digestibility of, 36, 66; formed by plants and destroyed by animals, 37; minimum quantity of, 38.
Foramen magnum, 580.
Force of endosmosis, 107.
Forgetfulness of dreams, 557.
Formic acid, 240.
Fourcroy on perspiration, 240.
Fourth pair of nerves, 334.
Fowl, digestive tract of, 58.
Franklin on heat, 380.
Frerichs on food, 35; on saliva, 44.
Frog, lungs of, 159; development of, 509.
Front view of skull, 585.
Future state, 551.

G.

GALILEO, 455.
Gall on brain, 259.
Gall-bladder, 199.
Galvani, experiments of, 443.
GANGLIA, structure of, 263; spontaneous function, 289; of sympathetic, 140, 264; of special sense, 315; cephalic, 607.
Gases of intestine, 82.
GASTRIC changes are subdivisions and assimilation of water, 62.
Gastric juice, 49, 50; quantity of, 52; acid of, 52, 54; relation of nervous influence to, 54.
Gelatine, 64, 65.
Gemmation, 534.
GENERATION, 515, 516; spermatozoa in, 517, 518.
Geographical distribution, 567.
Geography of plants, 472.
Geological changes, 480.
Geometrical modes of development, 457.
Germ-cell, 519.
Germinal membrane, 525; its layers, 527; vesicle and spot, 521.
Germination, 458; heat of, 176.
Gestation, 533.
Gibraltar, Straits of, 620.
Gills, 135, 150, 157.
GLAND, 189; type of, 189, 197; vicarious action of, 190; filtering action of, 190; parotid, 43; salivary, 43; submaxillary, 43; sublingual, 43; mesenteric, 89; ductless, 211; mammary, 225.
Glandular blood, change in, 190.
Globulin, 118.
Glosso-pharyngeal nerve, 338.
Glucose, 73.
Gluten, 33.
Glycerine, 245.
Goodsir on lymphatics, 97.
Graafian follicle, 521.
Gradual death, 561.
Grafting, 469, 535.
Graham on diffusion, 152, 154.
Greeks, 613; schools of, 617.
Growth, 511, 538, 540; conditions of, 465.
Guinea, negro of, 579.
Gum, digestion of, 71.
Gundelach on fat, 248.

H.

HABITS OF NATIONS, 566, 569; of insects, 605.
Hæmatin, 118; analysis of, 119.
Hæmatococcus binalis, 494.
Hair, 236.
Hall, discoveries of, 259.
Hallucination, 402.
Harvey on circulation, 130.
HEARING, sense of, 359; structure of organ of, 360; use of tympanum in, 364; auditory nerve of, 368.
HEART, 135; fibres of, 137; valves of, 138; development of, 135; of dugong, 136; action of nerves on, 140; statement of action of, 147; number of beats of, 130.
HEAT, 17, 18, 19, 20; check upon, 21, 22, 184; equilibrium of, 22; animal, 175, 177; carbonic acid, relation to, 19, 20, 176; variations, 178; diurnal, 178; extreme, endurable, 178; annual, 179; source of, 182; of light rays, 389; removed from muscle, 447; quantity for plants, 477; intensity and quantity of, 477; decline of, 488; relations of, 572; effect of, on skull, 590.
Heaths, absence of, from America, 474.
Height of man, 541.
Helmholtz on nerve, 266; on muscle, 445.
Hepatic artery, 200; cells, duct, vein, 200, 206.
Herbivora, 36.
Herculaneum, 465.
Hereditary transmission, 590.
Hermaphroditism, 574.
Hibbert on apparitions, 408.
Hippocratic face, 561.
Histogenetic digestion, 40, 63.
HISTORY a branch of Physiology, 604; European, 610; universal, 611; prognostics in, 612; comparative, 612.
Homogenesis and heterogenesis, 511.
Hot-blooded animals, 176.
Hottentots, 577.
Hubbenet, table by, 49.
Huber, 556.
Human groups, 568.

Humboldt on respiration, 158; on plants, 471.
Humors of the eye, 386.
Hunter on reflexa, 596.
Hutchison on respiration, 166.
Hybernating animals, 172, 183.
Hydra, 51, 52, 432, 501, 534.
Hydraulic action of auricle, 146.
Hydrochloric acid, 52, 62.
Hydrogen, use of, 17, 19.
Hypoglossal nerve, 343.

I.

Ideal type of man, 565.
Idiot, composition of brain of, 273.
Illusions, 402.
Imago, 511.
Immortality of the soul, 415.
Impersonal operations, 287.
Impressions, vestiges of, 288.
Improvability of man, 15.
Inanition, experiments on, 178, 243.
Inca Indians, 487.
Incombustible men, 634.
Independence and immortality of the soul, 285.
Independent action of each half of the brain, 328.
Index of prohibited books, 624.
Indians, 575; extinction of, 600.
India-rubber, diffusion through, 152.
Individuality, nature of, 468.
Indo-Europeans, 573.
Infancy of man, 538.
Inflorescence, heat of, 176.
Influence of agents on man, 563, 567, 571; of parent on child, 534.
Influential arc, 282.
Infusorials, heat of, 177.
Inosite, 447.
Inquisition, establishment of, 624.
Insalivation, 40.
Insanity of retina, 406.
Insect, digestive tract of, 58; cephalic ganglia, 271; nervous system, 271; respiration of, 157; development of, 510; structure and habit of, 603, 605; memory and metamorphoses of, 608.
Instantaneousness of dreams, 556.
Instinct distinguished from reason, 603.
Insubordination of one hemisphere, 329.
Intellect, maximum of, 591; centre of, 635.
Intensity, adjustment for variations of, in eye, 388.
Intensity of heat, 477, 572.
Interference, mechanism of, in ear, 372; of nervous impressions, 269.
Interstitial death, 244; movements, 151.
Intestine, length of, 42; salts and gases of, 82; digestion in, 63, 68, 81; contents, changes of, 83; section of wall of, 85; peristaltic movements of, 68; passage of food through, 67, 81; glands and secretion of, 69, 70.
Inverse problems, 284, 482.
Inverse Vision, 401; use of, 416.
Iris, 385.
Iron acted on by gastric juice, 50; source of, in blood-cells, 118.
Irrespirable gas, action of, 133, 169.
Isaacs on kidney, 217.

J.

Jackson on the ear, 373.
Jacob's membrane, 390.
Jeffreys on respiration, 165.
Jesuits, 624.
Jones, Bence, on urine, 221.
Jones, Handfield, on hepatic cells, 206.
Jones, W., on blood-cells, 117.

K.

Kaffirs, 577.
Kamtschatdale, 575.
Kangaroo, 59.
Kidney, 213; structure of, 214; tubuli uriniferi of, 215; circulation in, 215; development of, 214; vicarious action, 186.
Kiestine, 231.
Kolliker on skin, 420; on retina, 391; spleen, 211.
Koumiss, 80.
Krause on sebaceous secretion, 240.
Kreatine, 447.
Kune on bile, 203.

L.

Labyrinth, 361.
Lachrymal gland, 400.
Lacteals, 84, 86, 87, 91, 111; function of, 85; and lymphatics, connection of, with respiration, 100.
Lactic acid, 47, 52, 73, 74, 75.
Lacunæ of bone, 253.
Lamina spiralis, 359.
Landerer on perspiration, 240.
Languages, 357.
Laplander, 568.
Larva, 510.
Larynx, 353; double, of birds, 352; artificial, 355.
Lateral inversion, 397.
Lateral view of skull, 581.
Law, civil, 628.
Lawrence on the leg, 580.
Laycock on cephalic ganglia, 607.
Leg, 580.
Legumin, 33.
Lehmann on absorbed nitrogen, 39; peptones, 62; gastric solution, 66; gum, 72; urine, 75; quantity of blood, 113; blood crystals, 120; bile, 203; kiestine, 231.
Leidy on liver, 198.
Length of infant, 540; of sleep, 553.
L'Heritier on chyle, 96.
Lieberkuhn, follicles of, 69.
Liebig on lactic acid, 75; on fibrin, 98; on blood gases, 125.
Life, conditions of, 9, 12.
Light, nature of, 399; influence of, 459.
Lime, phosphate of, 35.

Liquor, sanguinis, 121; amnii, 530.
LIVER, 209; structure of, 199, 200, 201; development of, 191, 198; secretion, 203, 205; sugar, 123; production of sugar and fat in, 207; destruction of blood-cells in, 209; absorbed material goes to, 107; effect of, on complexion, 588. See Bile.
Localization of functions in brain, 324; of plants and animals, 482.
Longevity, 545.
Loss of perception of time, 332.
LUNGS, structure of, 157, 159, 160; capillaries of, 160; capacity of, 162; organic fibres of, 163; chemical changes in, 163. See Respiration.
Luther, Martin, vision of, 406.
Luxury, effect of, on skull, 588.
Lymph, 95; salts of, 96; flow of, 99.
Lymphatic glands, 94.
LYMPHATICS, distribution of, 97; function of, 96, 98; origin of, 529.

M.

MACEDONIAN CAMPAIGN, 620.
Machines, speaking, 356.
Madagascar, native of, 577.
Madder in bone, 256.
Magellan, voyage of, 624.
Male and female, comparison of, 546.
Malpighian bodies, 215; sac, removal of liquid from, 224.
Mammary gland, 224; development of, 225; action, 233.
Man, physical aspect of, 24; soul of, 25; maturity of, 542.
Margarine, 246.
Mariolatry, 631.
Marmots, 172.
Mastication, 40.
Matters received, 16; dismissed, 17.
Maturity of man, 542.
Meconium, 202.
Medulla oblongata, 304; functions of, 306.
Melloni on light, 389.
Membrana granulosa, 520; decidua, 525, 526.
Membranes, selecting power of, 107.
Memory of insects, 608.
Menstruation, 519.
Mental emotions, nature of, 290.
Mental hallucination, 402.
Mental qualities of different nations, 592.
Mental strength, maximum of, 544.
Mesencephalon, 292, 528.
Mesenteric glands, structure of, 89; plexuses, 350.
Metacetonic acid, 246.
Metamorphosis, 490.
Metamorphosis of batrachians, 509.
Metaphysics, 259.
Midnight sun, 476.
MILK, 29, 31, 32; casein of, 29, 227, 231; sugar of, 31, 227, 233; butter of, 31; salts of, 31, 228; lactic acid of, 31; effect of disease of, 33; composition of, 225, 226; analysis of, 226· vicarious secretion of, 228.
Mind, 24.
Miracles, true, 624.
Mitchell on diffusion, 152.
Mohammedanism, influence of, 629; spread of, in Africa, 597.
Moisture, influence of, 475.
Mongols, 574.
Monogamy, 594.
Monotheism, 601.
Mortality, 545.
Motion, ciliary, 431; muscular, 432.
Motor oculi nerve, 391.
Motor tract of brain, 319; of cord, 303.
Mouth, functions of, 40.
Mozambique, native of, 578.
Mucous membrane, 196; layer, 527.
Mucus, 43, 197; buccal, 43.
Mulberry mass, 523.
Muller on bile, 203; on vision, 391; on voice, 354.
Multipolar nerve-cell, 264, 268.
Municipal system, 623.
Muscæ volitantes, 404.
Muscle juice, 434, 437.
MUSCULAR FIBRE, structure of, 433; non-striated, 435; motion of, 432; movements, coordination of, 323; contraction of, 436; reparation of, 446; blood-vessels of, 440; contraction of, after death, 444; development of, 440; analysis of, 441; capillaries of, 439; effects of electricity on, 443.
Muza, his threat, 623.

N.

NAILS, 236.
Narwhal, 177.
Nations, origin of, 568; habits of, 569; progress of, 600.
Natural history, classification of, 506.
Negro, 579.
Neill on villi, 60.
NERVES, division of, 259; rate of conduction in, 265; sheath of, 261; fibres of, 262; function of fibres, 265; function of vesicles, 267; necessity of rest for, 272.
Nervous agency, magazines of, 268; transmission of, 265; retention of, 269; interference of, 269.
Nervous arcs, 277; condition for action, 283; centres, 290.
Nervous system, 258; controls heat, 186; development of, 292; metamorphosis of, 608; structure and functions of, 293.
Nervous vesicular matter, 260; ganglia, 263; activity, 267; tissue, composition of, 273; regeneration, 274.
Newport on insects, 309.
Newton, colored rings of, 105.
Nicolai on apparitions, 406.
Nightmare, 559.
Night sleep, 554.
Ninth pair of nerves, 338.
Nitrogen, use of, 16; in respiration, 171; protoxide of, 412.
Nodal lines, 371.
Non-striated fibre, 435.
Nose, 424.

Nucleated cells, circulation in, 131.
Nucleine, 117.
Nucleus, 493.
NUTRITION, 245, 252; connection with nervous agency, 186, 244; selecting power in, 245; three types of, 532; of carnivora and herbivora, 36.

O.

OBJECTIVE OPERATIONS, 287.
Ocelli, 380.
Octopus, nervous system of, 279.
Ocular spectra, 396.
Oculo-motor nerve, 333.
ODORS, sensibility to, 424; localization of, 426.
Odyssey, 613.
Oil, emulsifying of, 71; globules on villus, 88.
Old age, 545.
Oleaginous principles of food, 36, 81.
Oleine, 246.
Olfactory organ, mechanism of, 424.
Olivary bodies, 304, 314.
Omphalo-mesenteric duct, 530; vessels, 531.
Operations, plants are, 470.
Opium, effects of, 406.
Optic nerve, 391.
Orang, 581.
ORGANIC FORM, career of, 456.
Organic life, nerve of, 344.
Organic periodicities connected with heat, 179.
Organisms, metamorphosis of, 489.
Organization, principle of, 457.
Organized bodies, allotropism of, 188.
Organs of sense, 359.
Origin of nations, 568.
Ornithorynchus, 224.
Ossicles, 367.
Ossification, 255.
Osterlein on villi, 86.
Ostrich, stomach of, 59.
Oval skull, 586.
Ovarium, origin of ova in, 520; corpus luteum of, 522.
Ovisac, 520.
OVUM, 521; discharge of from ovary, 523; changes of, 524; segmentation of, 524.
Owen on the arm, 380; on skull, 532, 584.
Oxalic acid in urine, 222.
OXYGEN, uses of, 47, 101, 134; in respiration, 134, 163, 182; influence of, on blood, 126; changes albumen into fibrin, 101, 176; liberated by plants, 461.

P.

PACINIAN BODIES, 420.
Paganism, fall of, 622.
Paine, Professor, on plants, 478.
Pale people, disappearance of, in Europe, 634.
Palingenesis, 634.
Pancreas, 68; juice of, 68.
Pantheism, 288.
Papal government, 623.
Papillæ of skin, 419; of tongue, 428.
Parotid gland, 43.
Parturition, 533.
Par vagum, 340; influence of, on liver, 208.
Patagonians, 578.
Patella, nervous system of, 279.
Pathetici, 334.
Patina, 151.
Pelagian type, 579.
Pepsin, 49, 54, 55.
Peptones, 50, 53, 62.
Perception of time, loss of, 332.
Pericardium, 137.
Peristaltic movements, 53.
Peroxalate of iron decomposed by light, 461.
Persecution, result of, 624.
Persian empire, 616.
Perspiration, 238.
Persuasions, 544.
Peruvian, 576.
Peyer's bodies, 70, 94.
Phantasms, localization of, 415.
Philippine negro, 578.
Philosopher's stone, 633.
Philosophy, suppression of, 624.
Phœnicians, 619.
Phosphorus, 17, 23, 27, 32, 275.
Photographic effects of temperature, 393.
Phrenic nerve, 344.
Phrenology, 324.
PHYSIOLOGY, subdivisions of, 26; statical, 9; dynamical, 455.
Piles of Ritter, 277.
Pine, woody fibre of, 498.
Placenta, 526.
PLANTS, individuality of, 468; quantity of heat for, 467; secular changes of, 480; localization, 482.
Plasma, 121.
Plastic power, 459, 471.
Pneumogastric nerve, 340.
Polygamy, 594.
Polype, 51.
Polytheism, 601.
Pompeii, 465.
Pons varolii, 307.
Porcupine, 59.
Porpoise, stomach of, 59.
Portal circulation, 119, 134, 201, 202.
Ports of Egypt, opening of, 616.
Posterior roots of spinal nerves, 296.
Potassium, iodide of, experiments with, 47, 52.
Powder of projection, 633.
Pre-existence, sentiment of, 331.
Prevost and Dumas on muscle, 439.
Prichard on habits of men, 569; on skull, 580, 585.
Priestley on gaseous endosmosis, 151.
Primitive trace, 293, 527.
Primordial cell, 458.
Principle of organization, 457.
Printing, 358.
Prognathous skull, 586.
Protein bodies removed by urine, 220, 222.
Provençal on respiration, 155.
Psammetichus, 615.
Psychical powers, 327.

Ptolemies, 621.
Ptyaline, 45.
Pulsation of heart, 138; of arteries, 141.
Pulse, 139.
Pupa, 511.
Pyramidal skull, 586.
Pyramids, anterior and posterior, 304.

Q.

QUAIN ON ADIPOCIRE, 247.
Quality of sounds, estimation of, 375.
Quantity of heat, 477.
Quetelet, researches of, 15, 540.
Quick respiration, effect of, 168.
Quincey, De, on opium, 407.

R.

RADIAL fibre system, 390.
Radiation of heat, 185.
Ramlike action of heart, 147.
Rarefied air, effect of, 183.
Ray on insect habits, 606.
Reaumur on digestion, 55.
Reduction of temperature, 184.
Reflex action, 280; of insects, 609.
Reformation, 619, 625.
Registered impressions, 414.
Registering ganglia, 259; nerve arc, 281, 282.
Registry of sounds, 358.
Regnault and Reiset on respiration, 170.
Repair, necessity of, 244.
Reparation, 23.
REPRODUCTION of cells, 494; and development, 505; closes development, 513.
Reptile respiration, 158.
Residual air, 165.
RESPIRATION, 151, 156, 157, 170, 171, 174; water removed by, 168; gases of, 163, 167, 171, 176; movements in, 162; movements of air in, 163; number of movements, 162; influence of nervous agents on, 173; general statement of, 174.
Respiratory digestion, 63.
Restiform bodies, 304.
Resurrection of roses, 634.
RETINA, 390, 392, 394; structure of, 385, 390; disturbance of, 405.
Retzius on stomach, 61.
Reynoso on sugar, 208.
Rhakotis, 621.
Rhythmic contractions, 448.
Rigor mortis, 452.
Roman coins, 151.
Roman empire, 622.
Rotation of animals, 324.
Rudimentary organs, 491.
Rudimentary sounds, 325.
Rumford on clothing, 180.
Ruminant, stomach of, 59.
Running, 454.

S.

SABBATH DAY, 627.
Sahara, Desert of, 475.
Saladin, 631.
SALIVA, 43; action of, 46; quantity of, 44, 47; specific gravity of, 44; composition of 45; action of, in stomach, 46, 50; aeration by, 47.
Salivary glands, 43.
Salpæ, 537.
Salt, use of, 62.
Samoiedes, 568.
Sankey on brain, 325.
Sap, ascending, 87, 132.
Sarcolemma, 433, 438.
Scalæ of ear, 368.
Scherer on urine, 221.
Schlossberger on brain, 274.
Schmidt on albuminates, 39; on blood-cells, 119; on pneumogastric, 54; on pepsin, 55; on pancreatic juice, 68; on intestinal water, 83; on transudation, 95.
Schneiderian membrane, 424.
Schultz on muscle juice, 434.
Schwann on nerves, 261.
Science, contributions of Asia to, 596.
Sclerotic, 384.
Scot, Reginald, on spirits, 407.
Scott, Walter, on lying, 404.
Sebaceous glands, 227.
Secreted matters pre-exist in blood, 192, 195.
Secretion, 189; structures for, 193; by serous membranes, 193; by mucous, 196.
Seeing. See Vision.
Seguin on exhalation, 238.
Selecting power, 99.
Semicircular canals, 361, 364, 374.
Sensation of falling, 559.
Senses, 359.
Sensorium, 281, 319.
Sensory tract of cord, 303, 320; of brain, 320; ganglia, 282.
Sentiment of pre-existence, 331.
SEROUS fluids, 193.
Serous layer, 527.
Serous membrane, 193.
Serpents, legs of, 491.
Serum, salts of, 96.
Seventh pair, 337.
Sexes, mortality of, 545.
Shelter, imperfections of, 181.
Sight, cerebral, 401.
Silk-worm, 489.
Silver balls in digestion, 55.
Singing, 355.
Single vision, 395.
Sisocles, 582.
Sixth pair, 334.
Skeleton, 253, 580.
SKIN, 263; absorption by, 241; transpiration from, 185, 237; glands of, 235; exudation of, 185, 239.
SKULLS, examination of, 581; forms of, 582; classification of, 586; effect of heat on, 590.
Slack on circulation in cells, 132.
Sleep, 551.
Slow respiration, 168.
Smell, 423; condition of, 425.
Soap-bubble, diffusion through, 153.

Social mechanics, 602.
Society of insects, 604.
Sociology, comparative, 602.
Sodium, chloride of, 62; use of, 77.
Soemmering on leg, 580; spot of, 385, 397.
Soil, influence of, 476.
Solar plexus, 350.
Somnambulism, 557.
Song and speech, distinctions of, 352.
Soul, existence of, 283; independence of, 285, 548.
Sound, peculiarities of, 361; analogy of, to light, 379; articulate, 539.
Spain, colonial empire of, 632.
Spallanzani on food, 65.
Speaking machines, 356.
Species of plants, 479; changes in, 480, 484.
Speech, 539.
Spermatic fluid, 517.
Spermatozoa, 517; development of, 518.
Sperm-cell, 516.
Spherical aberration, 386.
Sphinx ligustri, 279, 308, 313, 607.
Spinal axis, 291.
Spinal cord, 294, 296; reflex action of, 300; comparative anatomy of, 300; divisions of, 296; connection of, with brain, 302; functions of, 303.
Spinal nerves, roots of, 303.
Spiracle of insect, 157, 352.
Spiral vessels, 498.
Spirit, 24.
Spirostreptus, 301.
Spissitude of blood, 169, 190.
Spitting, habit of, 47.
Spleen, 211.
Spongioles, 87, 466.
Spontaneous gemmation, 536.
Stages in introduction of air, 160.
Standards, fixed physiological, 13; tables of, 15.
Standing, 453.
Stapedius, 365.
Starch, 71.
Starvation, 182.
Stearine, 246.
Steenstrup on generation, 537.
Steno, duct of, 43.
Stereoscope, 397.
Still layer, 143.
Stomach, 41, 42; types of, 42; temperature of, 49; regions of, 60; histogenetic digestion of, 63; blood-vessels of, 102; mucous surface of, 50, 58; follicles of, 50; hydroid nature of, 51; trituration by, 55; secretions of, 48; various forms of, 59; movements of, 52.
Stove, warming by, 181.
Strecker on bile, 204.
Striated muscular fibre, 433, 436.
Stucco, endosmosis through, 107, 152.
Subdivisions influenced by heat, 79.
Subjective operations, 287; images, 398.
Submaxillary saliva, 43.
Suction, act of, 228.
Sudoriparous glands, 237, 238.
Sulphocyanide of potassium, 43.
Sulphur, 17, 23, 27.
Sunlight, 458; consumption of, 459; uses of, 466; variation of, 483.
Supplemental air, 165.
Supra-renal capsules, 214.
Swimming bladder, 157.
Sympathetic system, 344; peculiar fibres of, 262; origin of, 345; connected with spinal, 345; ganglia of, 346.
Sympathy depends on circulation, 112.
Synthetical mind of Asiatic, 592.
Syntonin, 438.
Systemic circulation, 134.

T.

Tadpole, experiments with, 489.
Talking birds, 352.
Taste, 427; nerves of, 429.
Taurine, 204, 208.
Teeth, 40; development of, 539.
Teleology, 415.
Temperature, effect of, on body, 177 on skull, 590; extremes, 178.
Tendons, 439.
Tensor tympani, 365.
Tenth pair of nerves, 340.
Testis, 516; secretion of, 517.
Thackrah on effect of want, 587.
Thenard on perspiration, 240.
Third pair of nerves, 333.
Thoracic duct, 90.
Tickling, 422.
Tidal air, 165.
Time, introduction of, into nervous mechanism, 269, 287.
Tin, trade in, 619.
Tissue, cellular, 497; muriform, 497; fibro-cellular, 497; vascular, 498; yellow fibrous, 499; white fibrous, 499; areolar, 499.
Tongue, 428.
Touch, structure of organ of, 417, 418; acuteness of, 420; in animals, 421; connected with vision, 419.
Tournefort on plants, 472.
Toynbee on ear, 365.
Tracts of spinal cord, 303; of brain, 318.
Tradescantia Virginica, circulation in, 132.
Traditions, 567.
Trains of thought, 329.
Transverse transmission in spinal cord, 298.
Trembley on hydra, 501.
Trigemini, 334.
Trisplanchnic nerve, 344.
Turner on smell, 427.
Twelfth pair, 343.
Twins, similarity of, 509.
Tympanum, 360, 365.
Type, ideal, of man, 565, 611.

U.

Unipolar nerve-cells, 263, 268.
Universal history, 611.
Urea, 447.
Urine, 218; composition of, 219; urea contained in it, 220; hippuric acid in, 222;

variability of, 219; sulphates in, 220; influence of diet on, 220; saline matter of, 220.
Uterine nutrition, 525; tubes, 525.
Utricle, 416.

V.

VACUUM, tendency to a, in respiration, 165.
Valentin on diffusion, 163; on perspiration, 229; on food, 39.
Valves of the heart, 138; sounds of, 139.
Valvulæ conniventes, 67.
Variable results from invariable causes, 270, 281.
Variations of heat, 179; effect of, on man, 180; of species of plants, 479.
VASCULAR area, 528; lamina, 528; system, origin of, 528.
Vegetable cells, circulation in, 132, 466.
Veins, absorption by, 84, 143.
Ventral cord, 300, 307, 609.
Ventricles, 138; force of, 139.
Venturi, principle of, 90.
Vermiform appendix, 63.
Vernois, table from, 53.
Vertebra, 528.
Vertebral canal, 294.
Vertebrata, 294.
Vertical view of skull, 582.
VESICULAR matter, composition of, 274; relations of, 315.
Vestibule, 374.
Vestiges of nervous impressions, 269, 288.
Vibration of sound, time measured by, 372.
Vicarious action, 47, 190.
Vierordt, 164.
Villi, 84, 86, 87, 110; cells of, 88; action of, 110.
Virchow on adipocire, 247.
VISION, 379; comparative anatomy of, 380; single and double, 395; inverse, 401.
Visions, 404; conditions of, 410.
Visual hallucinations, 403.
Vital principle, 24, 25, 55, 108, 456.
Vital spark, 460.
Vitreous humor, 385.
Vocal sounds, 352, 354.
Voice, 351; artificial larynx, 355; pitch of, 356.
Volkmann on muscular contraction, 276.
Volume of contracting muscle, 450.
Volvox globator, 513.
Von Bär, law of, 514.
Von Becker on carbohydrates, 39; on sugar, 73.
Vowels, 356.

W.

WALKING, 453.
Wallace on eye, 385.
Want, effect of, 587.
Warmth, artificial, 181; increased quantity required in sleep, 554.
Wasmann on pepsin, 55.
Wasp, habits of, 606.
Waste of tissue, 12, 23, 52.
WATER, use of, 16, 21, 22; solvent power of, 21; use in milk, 29; absorption of, 52; quantity exhaled, 168; cooling effect of, 185; of blood, 121.
Wave in blood, 141.
Weaning of plants, 465.
Weber on pelvis, 587; on quantity of blood, 113; on standing, 453.
Weight of man, 13, 14, 541; of infants, 14.
Whale, 491.
Wheatstone, 397.
Whispering, 356.
White on arm, 580.
Wigan on duality of mind, 329, 331.
Willow, 469.
Wilson on heart, 136.
Wine-making, 78.
Wolffian bodies, 150, 533.
Women in Asia and Europe, 593.
Words, origin of, 356.
Worship, public, influence of, 628.
Writing, 358, 610, 615, 635.

Z.

ZIGZAG appearance of muscle, 439.
Zimmerman on respiration, 170.
Zinc acted on by gastric juice, 50.
Zona pellucida, 523, 525.
Zoospores, 496.
Zygnema quininum, 515.

THE END.